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July 1989
Volume 13
Number 7

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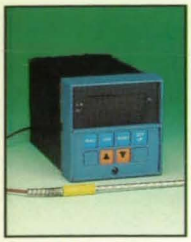

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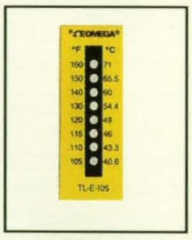

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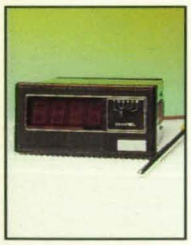

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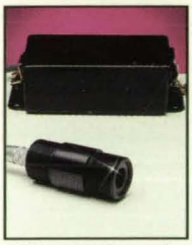

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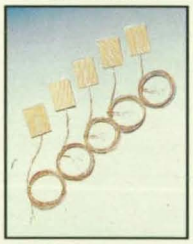

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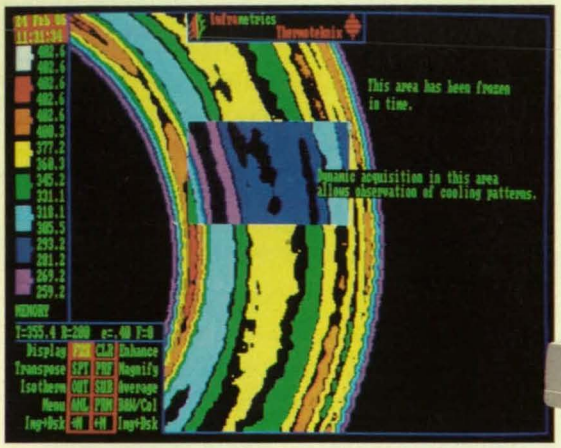
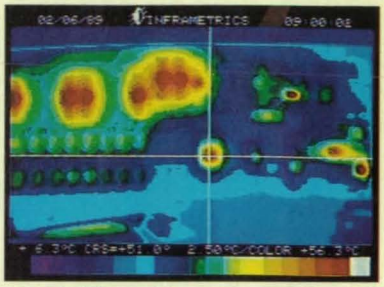


ThermaGRAM® image of an automotive brake rotor.



Model 600 provides spot temperatures of components on PC board. Line scan profiling, isotherm contouring and area measurement are all standard, without computer interface.

Model 600 on the lab bench...stalwart of sophisticated radiometers.

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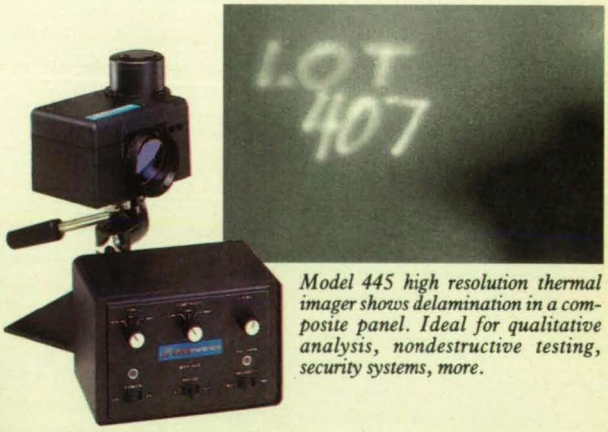
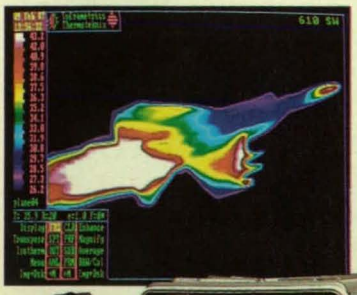


Model 445 high resolution thermal imager shows delamination in a composite panel. Ideal for qualitative analysis, nondestructive testing, security systems, more.



Model 610 acquires the dual-band IR signature of a fighter.

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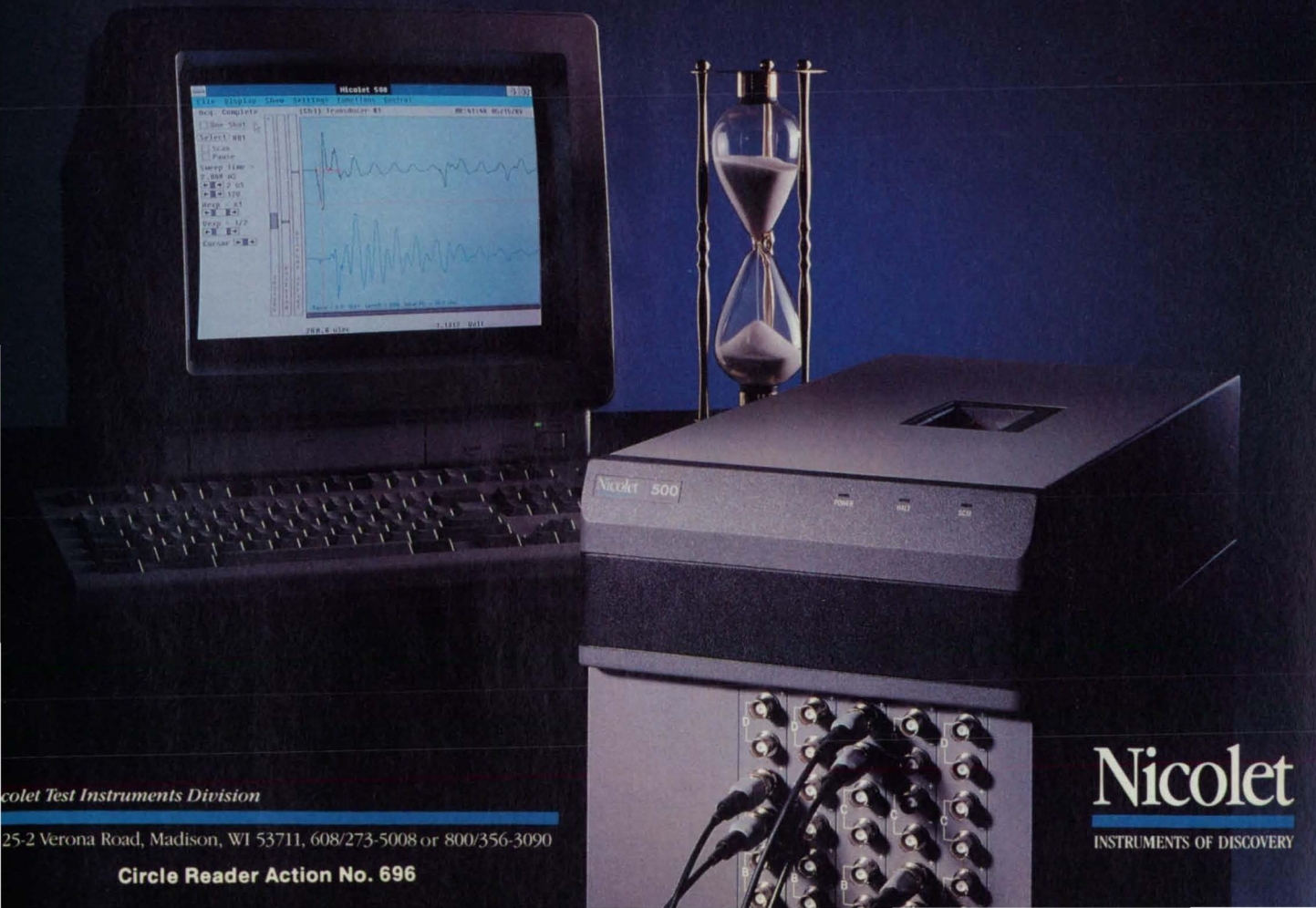

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JULY 1989
Volume 13 Number 7

SPECIAL FEATURE

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ABP BPA

Photo courtesy NASA

NASA is developing super-tough astronaut suits for Space Station extravehicular activity and for lunar and Mars surface exploration. The above photo shows underwater testing of the Ames Center's new X-5 space suit, which is made of aluminum and stainless steel with no soft fabric parts. See page 16.

DEPARTMENTS

On The Cover: A nuclear-electric-propulsion cargo vehicle approaches Mars in this artist's conception. NASA contemplates using electrically-driven vehicles to support a manned Mars mission early next century. Turn to page 16.

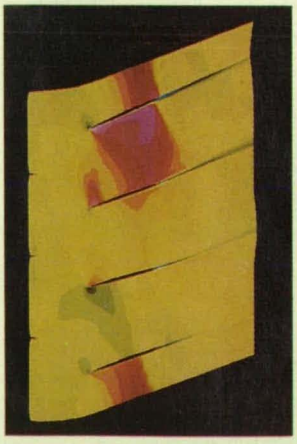

Photo courtesy NASA

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Lewis Center researchers have simulated the unsteady flow surrounding advanced turboprop airfoil sections. See page 66.

New This Month

For your convenience, we have combined the Subscription/Technical Support Package Form and the Reader Action Card into a single, easy-to-use form (page 81).

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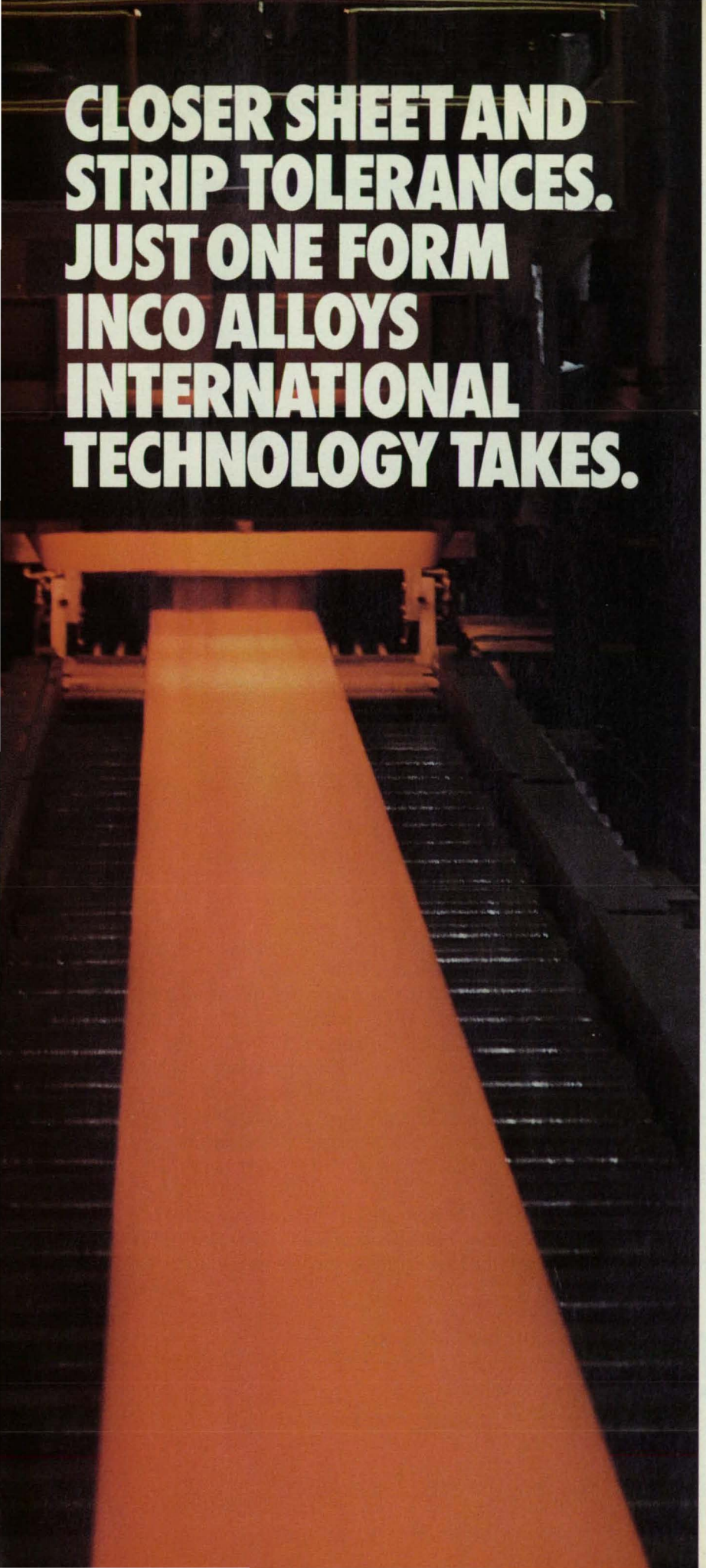

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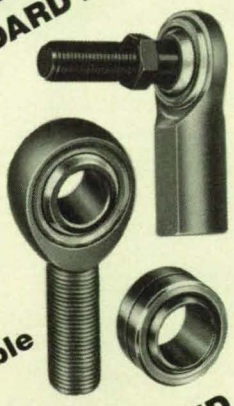

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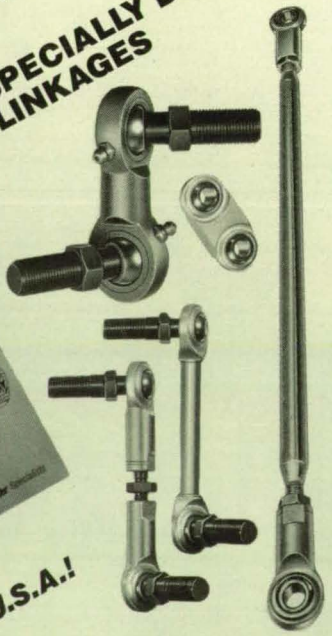

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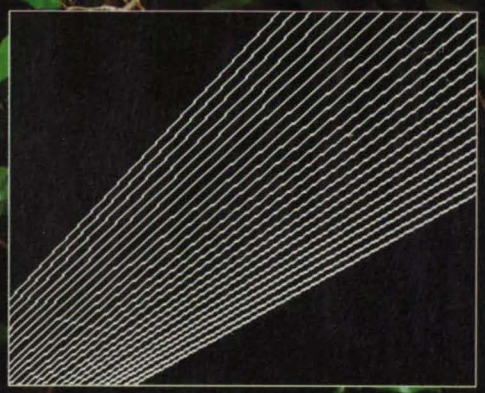
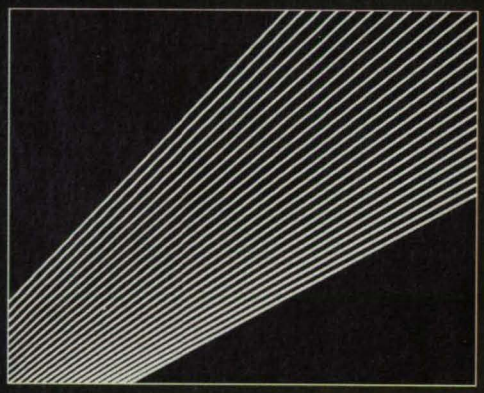


The competition's 1024 x 780 pixel display



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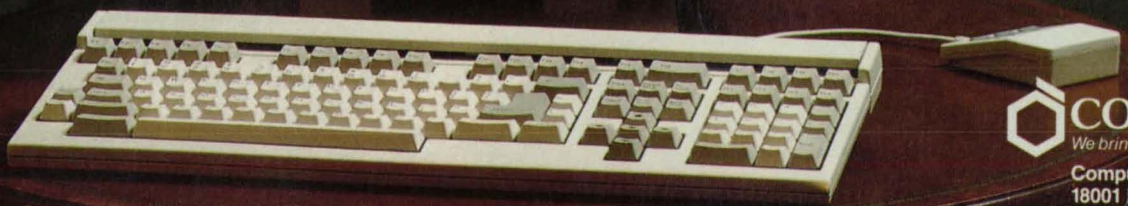

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New Product Ideas

New Product Ideas are just a few of the many innovations described in this issue of *NASA Tech Briefs* and having promising commercial applications. Each is discussed further on the referenced page in the appropriate section in this issue. If you are interested in developing a product from these or other NASA innovations, you can receive further technical information by requesting the TSP referenced at the end of the full-length article or by writing the Technology Utilization Office of the sponsoring NASA center (see page 14). NASA's patent-licensing program to encourage commercial development is described on page 14.

Carbon/Carbon Panels Cooled by Heat Pipes

A new cooling structure considered for hypersonic aircraft combines high-temperature heat-pipe and carbon/carbon technologies. With new coatings that are being developed, maximum operating temperatures will reach 3,000 °F (1,649 °C). (See page 64).

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Heat-Flux Sensor for Hot Engine Cylinders

A heat-flux sensor includes a buried wire thermocouple and a thin-film surface thermocouple, both made of platinum and platinum with 13 percent rhodium. The sensor is intended for use in a ceramic-insulated, low-heat-rejection diesel engine at temperatures of about 1,000 K. (See page 48).

Making a Precisely Level Floor

A floor-pouring procedure, mainly for laboratories and special installations, yields a large surface that is level, smooth, and hard. The method has been used to fabricate a 1,200-ft^2(111-m^2) floor that varies locally in elevation less than 0.015 in. in 16 horizontal in. (0.038 cm in 0.41 horizontal m). (See page 78).

Circularity-Measuring System

A shape gauge and an associated computer constitute a system that measures the deviations of large cylinders from roundness. The system can be used to measure the straightness, roundness, or complicated shapes of such large geometrical objects as the surfaces of aircraft, the hulls of ships, and buildings. (See page 83).

Field-Sequential Color Converter

An electronic conversion circuit enables the display of signals from a field-sequential color-television camera on a color video camera. The field-sequential technique of encoding color video signals reduces the size, weight, and power consumption of a video camera by requiring only one image sensor instead of the usual three. (See page 24).

Whistle Gauge Measures Flow and Temperature

A simple, rugged gauge is used to measure the speed of flow and the temperature of steam or other gas flowing through pipes of arbitrary diameter. The gauge is a specially designed, instrumented whistle that generates intense sound for use in the measurements. (See page 65).

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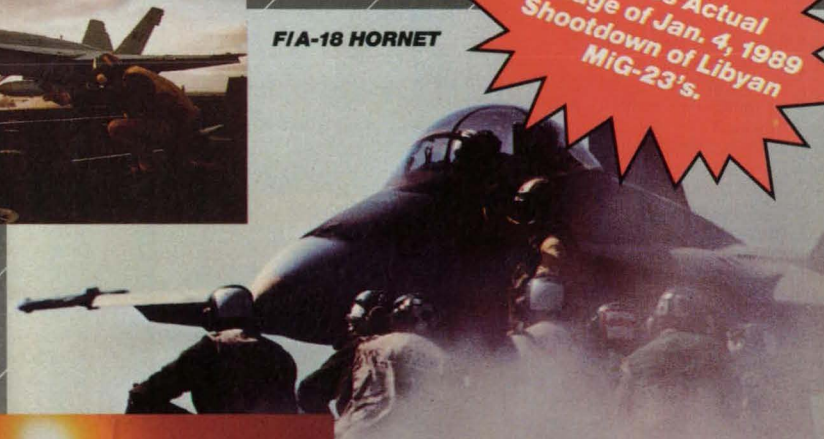

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If you're a regular reader of TECH BRIEFS, then you're already making use of one of the low- and no-cost services provided by NASA's Technology Utilization (TU) Network. But a TECH BRIEFS subscription represents only a fraction of the technical information and applications/engineering services offered by the TU Network as a whole. In fact, when all of the components of NASA's Technology Utilization Network are considered, TECH BRIEFS represents the proverbial tip of the iceberg.

We've outlined below NASA's TU Network—named the participants, described their services, and listed the individuals you can contact for more information relating to your specific needs. We encourage you to make use of the information, access, and applications services offered by NASA's Technology Utilization Network.

How You Can Utilize **NASA's Industrial Applications Centers**—A nationwide network offering a broad range of technical services, including computerized access to over 100 million documents worldwide.

You can contact NASA's network of Industrial Applications Centers (IACs) for assistance in solving a specific technical problem or meeting your information needs. The "user friendly" IACs are staffed by technology transfer experts who provide computerized information retrieval from one of the world's largest banks of technical data. Nearly 500 computerized data bases, ranging from NASA's own data base to Chemical Abstracts and INSPEC, are accessible through the ten IACs located throughout the nation. The IACs also offer technical consultation services and/or linkage with other experts in the field. You can obtain more information about these services by calling or writing the nearest IAC. User fees are charged for IAC information services.

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If you represent a public sector organization with a particular need, you can contact NASA's Application Team for technology matching and problem solving assistance. Staffed by professional engineers from a variety of disciplines, the Application Team works with public sector organizations to identify and solve critical problems with existing NASA technology. **Technology Application Team, Research Triangle Institute, P.O. Box 12194, Research Triangle Park, NC 27709. *Doris Rouse, Director,* (919) 541-6980**

How You Can Access Technology Transfer Services At NASA Field Centers:
Technology Utilization Officers & Patent Counsels—Each NASA Field Center has a Technology Utilization Officer (TUO) and a Patent Counsel to facilitate technology transfer between NASA and the private sector.

If you need further information about new technologies presented in *NASA Tech Briefs,* request the Technical Support Package (TSP). If a TSP is not available, you can contact the Technology Utilization Officer at the NASA Field Center that sponsored the research. He can arrange for assistance in applying the technology by putting you in touch with the people who developed it. If you want information about the patent status of a technology or are interested in licensing a NASA invention, contact the Patent Counsel at the NASA Field Center that sponsored the research. Refer to the NASA reference number at the end of the Tech Brief.

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If You Have a Question . . . **NASA Scientific & Technical Information Facility** can answer questions about NASA's Technology Utilization Network and its services and documents. The STI staff supplies documents and provides referrals. Call, write or use the feedback card in this issue to contact: **NASA Scientific and Technical Information Facility,** Technology Utilization Office, P.O. Box 8757, Baltimore, MD 21240-0757. *Walter M. Heiland, Manager,* (301) 859-5300, Ext. 242, 243

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Image courtesy of Computervision Corp.

Circle Reader Action No. 337

Over the next decade, Project Pathfinder will develop the enabling technologies for bold new space missions.

Illustration courtesy NASA

Project Pathfinder

NASA Plans For Man's Next "Giant Leap"

As the nation commemorates the historic Apollo moon landing, NASA is preparing for the next "giant leap" into the solar system. In partnership with U.S. industry and universities, the Space Agency has embarked on a major research project called "Pathfinder" that will develop the enabling technologies for piloted missions to Mars, lunar outposts, and the advanced robotic exploration of the solar system.

Project Pathfinder will provide a base for wise decisions on future missions and goals, said program manager John Mankins. "We'll address the critical technology issues and assess the costs involved before any final decisions are made regarding mission designs," he explained. "That will save a lot of time and money in the long run."

Pathfinder complements the ongoing Civil Space Technology Initiative (CSTI), which focuses on technologies needed for operations in low Earth orbit. Through pathfinder, NASA's Office of Aeronautics and Space Technology

will develop capabilities in the areas of surface exploration, space transfer systems, in-space operations, and human factors.

Surface Exploration

One objective of the Surface Exploration Program is to develop a robotic roving vehicle that would explore the Martian terrain as a precursor to manned missions. Rovers could support construction of a moon base as well.

Under a contract with NASA's Jet Propulsion Laboratory, Martin Marietta is studying designs for both wheeled and walking rovers. One promising concept is the "walking beam," a collapsible T-beam structure designed for easy storage on a lander spacecraft. As envisioned, the vehicle will travel at about 300 feet per hour, its telescoping legs able to step up five feet to avoid obstacles. Onboard computers will detect boulders, craters, and other hazards and send the rover instructions to avoid them. Along the way, the rover will use its scientific instruments and robotic arms to test soil and rock samples, the most interesting to be returned to Earth via small rockets.

The vehicle's route will be preplanned using information captured by the Mars Observer spacecraft. Slated for launch in 1992, the craft will orbit Mars, mapping the planet in detail and gathering data on its atmosphere, magnetic field, and soil composition.

The Mars Rover/Sample Return study will guide development of such key technologies as surface mobility, onboard autonomy, and power generation. Pathfinder will integrate the autonomous rover research performed by Carnegie Mellon University's Robotics Institute, and will build upon the Department of Energy's modular radioisotope thermoelectric generator (RTGs) program. Modular RTGs are viewed as the most likely power source for robotic rovers—if more efficient thermoelectric conversion materials can be produced.

In concert with the rover project, NASA will develop methods for acquiring, analyzing, and preserving surface samples. This will require imaging and ranging devices to pinpoint sample location; semi-autonomous machines to pick up and/or drill samples; onboard instruments to analyze the sample's chemical and physical properties in order to determine it's scientific worth; and storage systems resistant to extreme temperatures, radiation, and vibration for the long journey back to Earth.

Space Transfer

Pathfinder's Transfer Vehicle Program will provide the means for transporting robots and humans to and from planets, and for transfer between different Earth orbits. One of NASA's main goals is to minimize the propellant mass needed to reach orbit, land on a planet, and return to Earth, which will reduce launch costs while providing more space for scientific payloads. NASA hopes to accomplish this by developing highly efficient chemical and electric propulsion systems, and by employing the fuel-saving technique of aerobraking, in which the atmospheres of Earth or other solar system bodies are used to slow a spacecraft in order to achieve the necessary velocity for orbiting the body.

NASA's Lewis Research Center will lead the propulsion work. One objective is to build liquid oxygen/hydrogen engines that are fault-tolerant and serviceable in space. Research will focus on high-heat combustors, high-pressure turbomachinery, and integrated diagnostic sensors and controls.

For electric propulsion systems, Lewis will develop advanced magnetoplasmadynamic (MPD) and ion thrusters. NASA wants to apply electric propulsion to cargo vehicles supporting a manned Mars mission. Studies have shown that high-performance electric propulsion with a specific impulse over 4000 sec at multi-megawatt power levels could significantly reduce the amount of onboard propellant a cargo vehicle would need while still providing acceptable transit time performance. Key technical issues to be resolved include MPD cathode longevity, the ability to create self-induced magnetic fields at megawatt levels, and the availability of high-fidelity ground test facilities.

In-Space Operations

Both piloted and robotic missions to Mars would use small craft to shuttle to and from the planet's surface. Because round-trip-light time delays in deep space communications will preclude real-time Earth-based control of these vehicles, NASA must develop automated rendezvous and docking techniques. This will require advanced sensors for long- and short- range tracking and relative navigation from several hundred kilometers down to the contact point of docking. A prototype laser docking sensor being built for a 1991 flight experiment shows promise for ranges from zero to more than five kilometers. Space Agency researchers will work to improve the range of laser-based sensors while reducing power, weight, and volume requirements, and will explore other candidate sensors, including millimeter-wave radar and robotic video image recognition systems.

Advanced sensors also will be needed for in-space robotic assembly and construction of fuel depots, repair "garages," and other orbiting structures that will support future solar system missions. Under the Langley Center's direction, robot end effectors and holding fixtures will be created for precision welding, bonding, and mechanical joining of parts in space. NASA additionally will develop transporters, space cranes, and other methods for telerobotically manipulating and positioning the parts to be joined, and will also evaluate methodologies for in-space construction of generic spacecraft parts, such as aerobrakes and pressurized modules, that can be applied to many different missions.

Assembling and constructing structures in space will limit dependence on Earth-to-orbit launch vehicles, as will the development of surface pilot plants to process extraterrestrial resources. Such facilities would dramatically reduce the amount of material launch vehicles would need to cart into space. For example, lunar rocks and soil contain an abundance of oxygen, metals, and glasses that could be processed into life support supplies, fuels, construction materials, and shielding for general use in space as well as on the lunar surface. This might include resupply of orbiting space stations, outfitting solar system missions originating from the moon, and supporting a lunar settlement. In coming years, NASA will demonstrate telerobotic methods for collecting, handling, and sorting lunar materials, and will validate various material processing technologies, including a process for creating fiberglass and bricks from lunar soil through heating and compaction.

Humans In Space

Pathfinder's Humans In Space thrust will provide the engineering systems to enable effective performance and good health during long-duration missions. One element is directed towards technologies that will permit humans to operate for extended periods outside the protection of their pressurized habitats. It focuses on developing lightweight yet rugged extravehicular activity (EVA) suits with portable life support systems. NASA is currently

The "walking beam" would move nimbly over Martian terrain, collecting soil and rock samples for eventual analysis on Earth.

Illustration courtesy Martin Marietta Corp.

Three Things You Shouldn't Have To Share At The Office

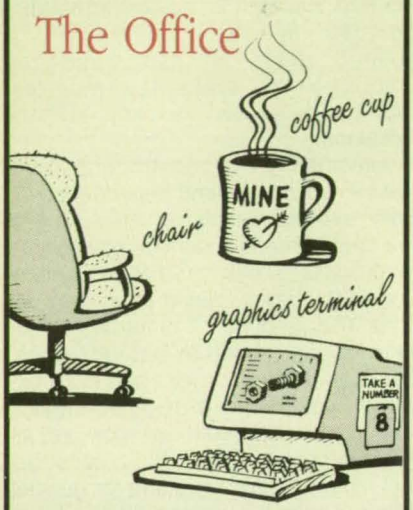

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Illustration courtesy NASA

High-energy aerobraking would reduce fuel consumption and allow for larger payloads on future solar system exploration missions.

evaluating two prototype EVA suits developed by the Ames Research Center and Johnson Space Center. Ames' version is made of aluminum and stainless steel with no soft parts that could be damaged by atomic oxygen or by rocket propellants spilled into space, while the Johnson Center suit features both hard and soft elements and stresses wearer comfort. Both models eliminate the existing requirement that astronauts prebreathe pure oxygen to dispel nitrogen from body tissues before beginning EVA, and therefore would operate at much higher pressures than current Space Shuttle EVA suits. A review team will select one suit or the other, or possibly a new hybrid design that combines elements of both, for futher development in Pathfinder.

Another part of the Humans In Space effort involves developing technologies to accomodate human physiological requirements and adaptive changes during long-term confinement, exposure to unnatural gravity and dangerous ionizing radiation, and unaccustomed risk and stress. Research into human capabilities and limitations for physical and cognitive work will be conducted; in addition, vital technologies such as artificial gravity systems and radiation shields will be explored.

A third aspect of the program deals with techniques for air revitilization, water reclamation, and waste treatment. These will be integrated in a physical-chemical closed-loop life support system that will substantially reduce the mass of consumables and, hence, resupply costs for long-duration missions. A concurrent effort will construct a bioregenerative life support system which will produce food, potable water, and a breathable atmosphere from metabolic and other wastes. Photosynthesis will be used to generate food, with resultant production of oxygen and water and removal of carbon dioxide.

Spinoff Benefits

Pathfinder technologies will find broad use outside of NASA, both on Earth and in space. Planetary rover technologies such as autonomy and mobility may be applied to toxic waste disposal and firefighting, for example, while in-space assembly and construction methods will be of great benefit for future commercial communications satellites.

Moreover, space transfer technologies such as advanced chemical propulsion and aerobraking, although specialized for space applications, will provide further engineering expertise in materials and structures, as well as in design of high-speed aircraft. And Humans-In-Space studies of physical-chemical and bioregenerative life support systems will provide insight on how ecological systems work, and perhaps why they fail.

Across a wide spectrum of disciplines, Pathfinder will "push American technology forward," said Mankins, "just as the Apollo program did in the 1960s." □

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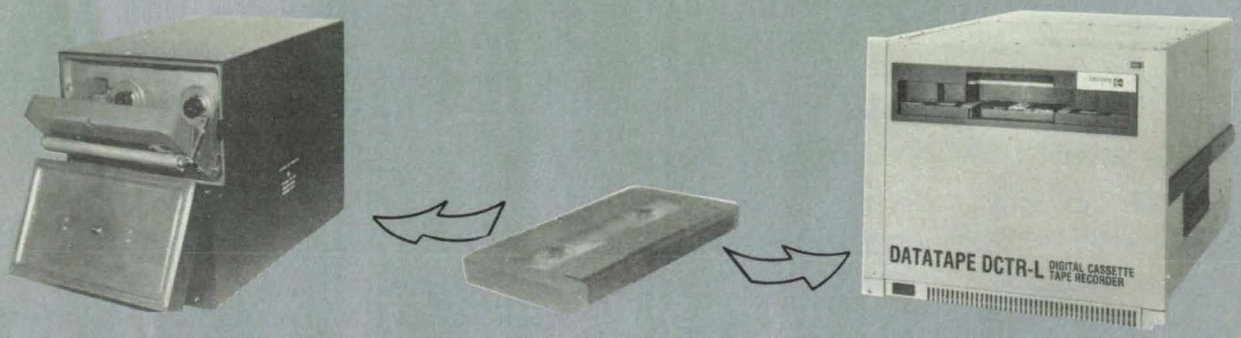

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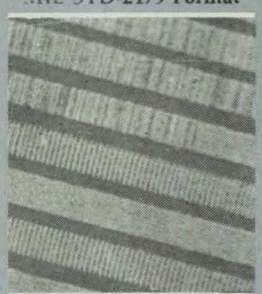

0° Azimuth Recording

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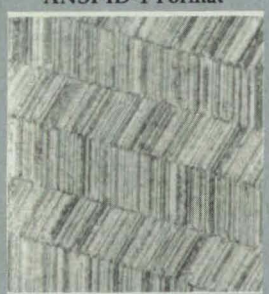

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Cassette Compatibility..... D-1S, D-1M, D-1L
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	16 μm TAPE	13 μm TAPE
D-1S	1.1×10^{11} bits	1.5×10^{11} bits
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D-1L	7.6×10^{11} bits	1×10^{12} bits

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Circle Reader Action No. 374

Electronic Components and Circuits

Hardware Techniques, and Processes

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24 Field-Sequential Color Converter

28 Hotspot Endurance of Solar-Cell Modules

30 Twisted Pair of Insulated Wires Senses Moisture

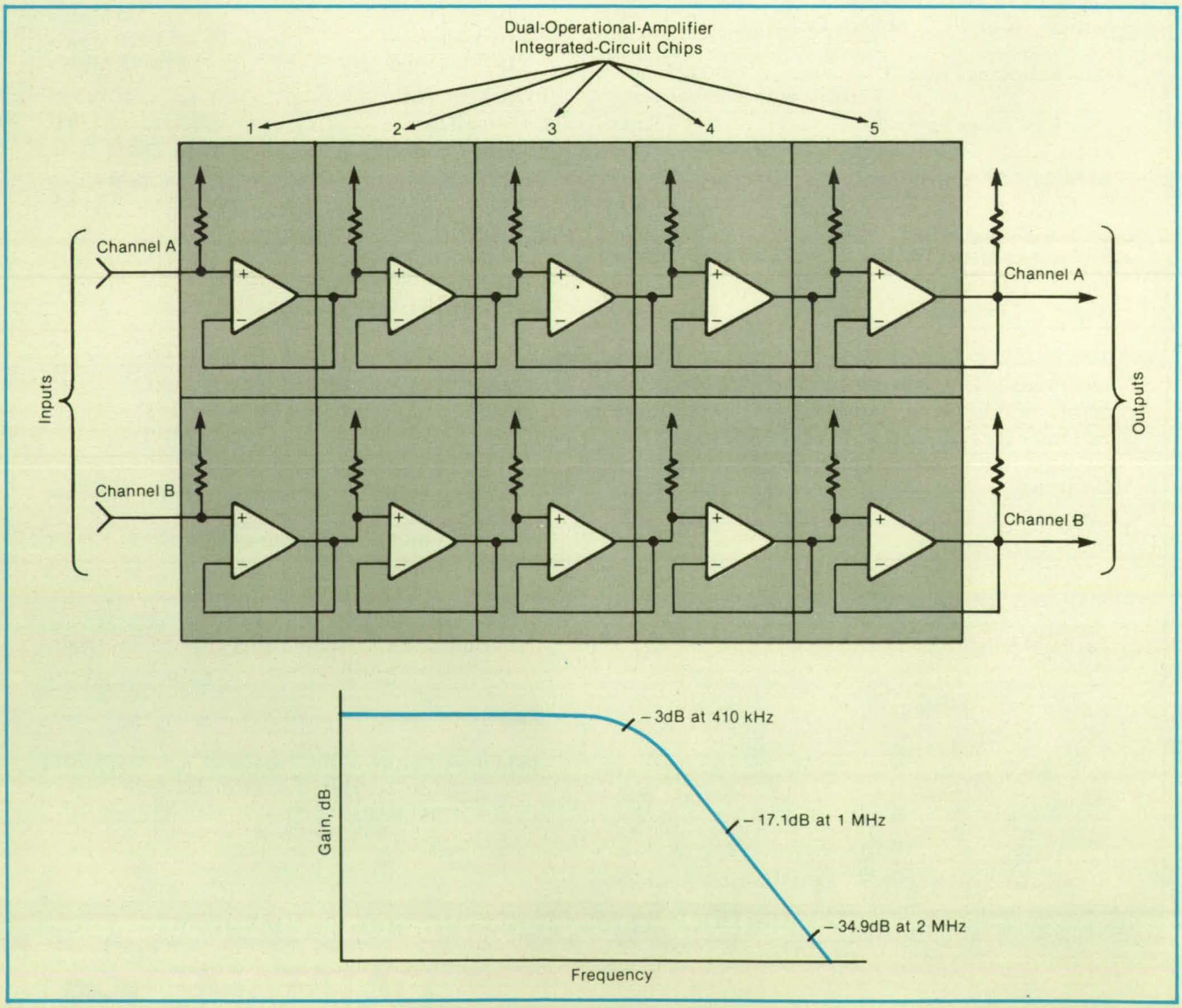
Multichannel, Active Low-Pass Filters

Multichannel integrated circuits are cascaded to obtain matched characteristics.

NASA's Jet Propulsion Laboratory, Pasadena, California

The gain and phase characteristics of the channels of a multichannel, multistage, active, low-pass filter can be matched by making the filter of cascaded multichannel integrated-circuit operational amplifiers. This concept takes advantage of inherent equality of electrical characteristics of nominally-identical circuit elements made on the same integrated-circuit chip. Moreover, the characteristics of the channels vary identically with changes in temperature.

The concept was motivated by the design requirements of a radar-target simulator for use at frequencies from 200 Hz to 450 kHz to process Doppler modulation. The gain and phase characteristics of the two channels in the simulator had to be as



This **Cascade of Dual-Operational-Amplifier Integrated Circuits** constitutes a dual-channel active low-pass filter having a 410-kHz 3-dB-cutoff frequency and a 30-dB/octave rolloff. The gain and phase of channel A match those of channel B. Although the operational amplifiers in this filter are adjusted for unit gain, a larger gain would produce a similarly flat response in the passband.

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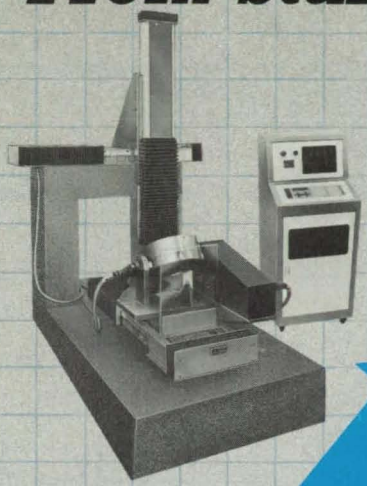

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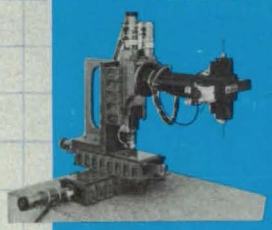

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closely matched as possible; otherwise, gain and phase errors would degrade the rejection of sidebands.

Each stage in each channel of the active filter consists of an operational amplifier set for unit gain. The operational amplifier provides a flat response in the passband and a smooth transition from passband to stopband. Five two-channel operational amplifiers are cascaded to produce the required cutoff frequency and 30-dB/octave rolloff rate for each channel (see figure).

If such a filter were made of discrete components, it would be extremely bulky because of the sizes of components required for operation at the low frequencies in the passband. Moreover, it would be difficult and expensive to match every part with the corresponding part in the other channel.

If additional matched channels are needed, chips containing more than two operational amplifiers apiece (e.g., commercial quad operational amplifiers) could be used. The concept is applicable to a variety of equipment requiring matched gain and phase in multiple channels — radar, test instruments, communication circuits, and equipment for electronic countermeasures.

This work was done by James J. Lev of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 142 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 14]. Refer to NPO-17290.

Efficient Cavity-Dumped, Frequency-Doubled Nd:YAG Laser

Undoubled light is returned to the primary cavity.

NASA's Jet Propulsion Laboratory, Pasadena, California

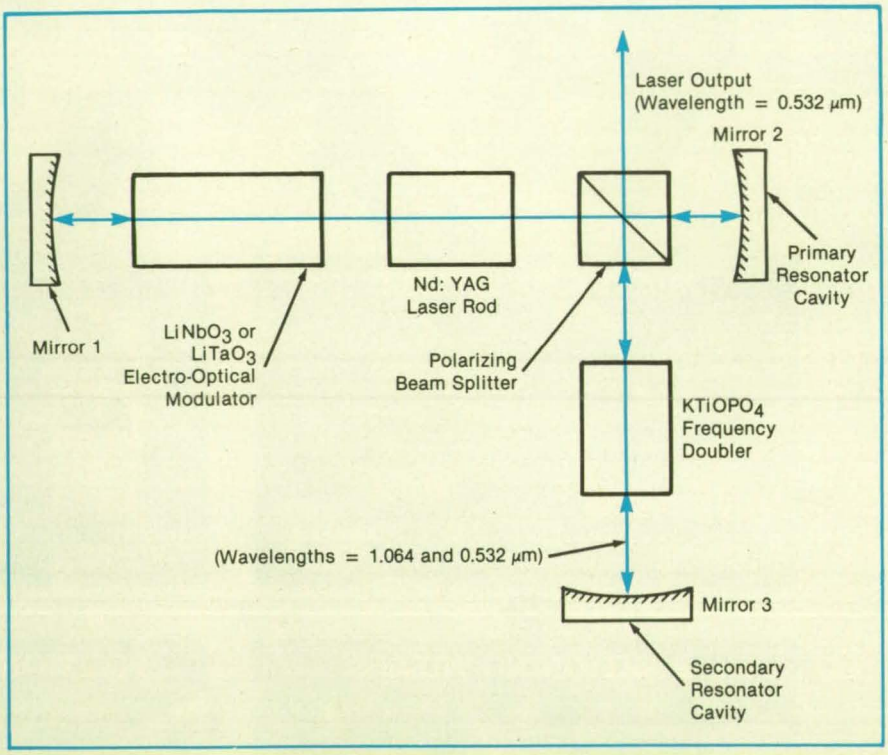
A new design is expected to increase the efficiency of a cavity-dumped, frequency-doubled Nd:YAG laser. The frequency-doubling crystal is placed outside the primary resonator cavity to reduce the loss that it would cause if placed there, and the light in the external frequency-doubling cavity at the fundamental laser frequency (the "undoubled" light) is returned to the primary resonator cavity to contribute additional laser gain.

The primary resonator cavity is bounded by mirrors 1 and 2 and contains an electro-optical modulator, an Nd:YAG laser rod, and a polarizing beam splitter (see figure). Mirrors 1 and 3 define the secondary resonator cavity, part of which coincides with part of the primary resonator cavity and the rest of which contains the external frequency-doubling crystal.

As in normal cavity dumping, energy at the fundamental laser frequency (wavelength of 1.064 μm) is stored in the photon field of the primary resonator; pulses of light are extracted from the primary resonator by application of switching voltage pulses to the electro-optical modulator. The polarizing beam splitter polarizes horizontally the initial beam of light on the optical path of the primary resonator.

The application of the transverse switching electric field to the electro-optical modulator introduces a quarter-wave retardation to the beam. A double pass through the modulator causes a half-wave phase shift and concomitantly rotates the polarization to vertical. The vertically polarized light is reflected by the beam splitter out of the primary resonator and through the frequency-doubling crystal, which rotates the polarization of the doubled portion of the light by 90°.

Mirror 3 reflects the doubled and undoubled light back toward the beam splitter, which is dichroic and allows the doubled light to pass through. Because the undoubled reflected light is still vertically polarized, it is reflected by the beam splitter back into the primary resonator. As long as the electric field remains on in the electro-optical modulator, this returned light is rotated back to horizontal polarization and returned to the initial beam. Applications of this laser are foreseen in data communications, laser ranging, studies of the atmosphere, remote sensing, and laboratory studies.



In the **Cavity-Dumped, Frequency-Doubled Nd:YAG Laser**, the frequency is doubled outside the primary laser resonator, and the portion of fundamental-frequency light not used by the doubler is returned to the primary laser cavity to increase the efficiency.

This work was done by D. L. Robinson and D. L. Sipes of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 79 on the TSP Request Card.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

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Refer to NPO-17286, volume and number of this NASA Tech Briefs *issue, and the page number.*

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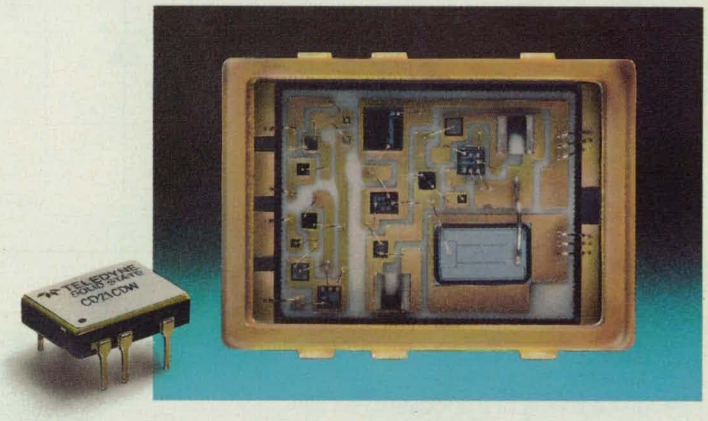


ACTUAL SIZE CERAMIC PACKAGE

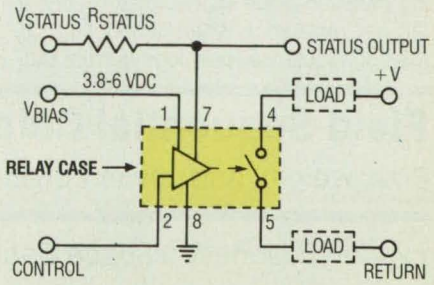
PART # CD21CDW

Review the electrical characteristics and call us for immediate application assistance.*

ELECTRICAL CHARACTERISTICS (–55°C to +105°C unless otherwise noted)				
	Min	Max	Units	
Bias Voltage (V_{BIAS})	3.8	6.0	V_{DC}	See Note 1
Bias Current (I_{BIAS})		15.0	mA	$V_{BIAS} = 5 V_{DC}$
Control Voltage (V_{IN})	0	18.0	V_{DC}	
Control Current (I_{IN})		250	µA	$V_{IN} = 5 V_{DC}$
Turn-Off Voltage $V_{IN\,(OFF)}$	3.2		V_{DC}	
Turn-On Voltage $V_{IN\,(ON)}$		0.3	V_{DC}	
Continuous Load Current		1.2	A	–55°C to +25°C
I_{LOAD} @ 60 VDC		0.7	A	+85°C
Output Trip Current (I_{TRIP})	2.4 (Typ.)		A	+25°C, 100ms
On-Resistance (R_{ON})		0.65	Ohms	
Turn-On Time (T_{ON})		1.5	ms	
Turn-Off Time (T_{OFF})		0.25	ms	
Status Voltage (V_{STATUS})	1	18	V_{DC}	
Status Current (I_{STATUS})		2	mA	$V_{SAT} \leq 0.3 V_{DC}$ See Note 2

Notes:
1. Series resistor is required for bias voltages above $6V_{DC}$. $RS = (V_{BIAS} - 6 V_{DC})/15$ mA
2. A pull up resistor is required for the status output. $R_{STATUS} = (V_{STATUS} - 0.3)/I_{STATUS}$
3. Output will drive loads connected to either terminal (sink or source).
4. Status circuit is a built-in test feature checking the input circuitry of the relay. Status output is low (on) when the input is on.

All power FET relays may drive loads connected to either positive or negative referenced power supply lines (source or sink modes).



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Circle Reader Action No. 537

Synchronous Half-Wave Rectifier

An active circuit acts like a highly efficient diode.

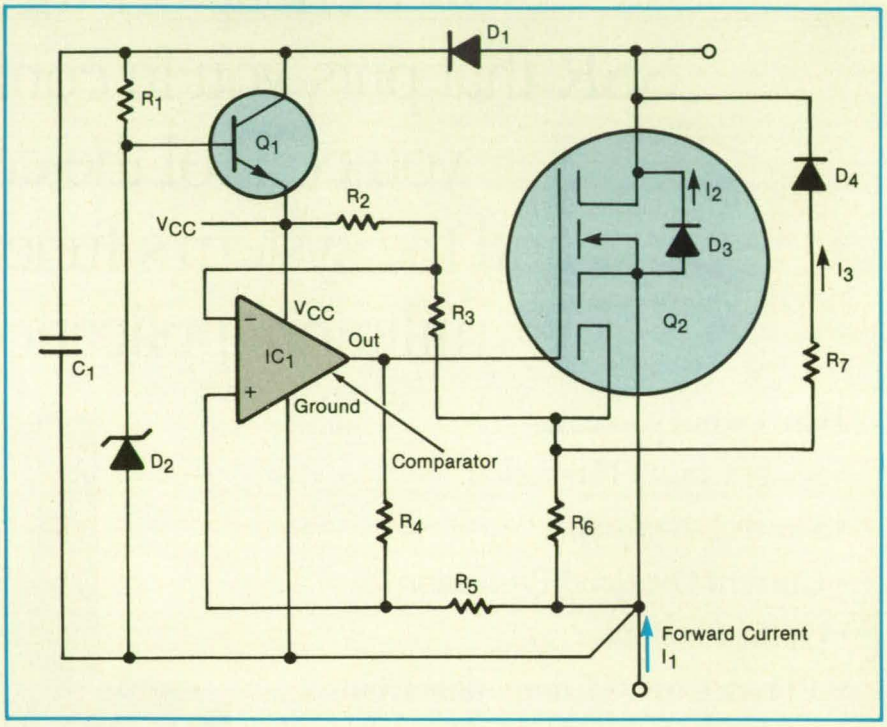
NASA's Jet Propulsion Laboratory, Pasadena, California

A synchronous rectifying circuit behaves like a diode that has an unusually low voltage drop during forward-voltage (conducting) half cycles. The circuit would be particularly useful in power supplies with potentials of 5 Vdc or less, where the normal forward-voltage drops in ordinary diodes can be unacceptably large. The circuit could be fabricated as a monolithic assembly or as a hybrid.

The circuit (see figure) includes main-current-controlling field-effect transistor Q_2, which is controlled in part by current-sensing comparator IC_1. The combination of capacitor C_1, resistor R_1, Zener diode D_2, and transistor Q_1 constitutes a conventional voltage-regulating power supply for IC_1. C_1 is charged through diode D_1 during the reverse (nonconducting) half cycle and discharges through the regulator so that the regulator supplies a nearly constant voltage, V_{CC}, to IC_1 throughout the cycle.

During the reverse half cycle, the combination of positive bias from voltage divider R_2, R_3 and the more negative input to the positive terminal through R_5 forces the output of the comparator low. Because the output of the comparator is fed to the gate of Q_2, Q_2 remains turned off.

At the beginning of the forward half cycle, I_2 begins to flow in diode D_3 (a parasitic integral body diode in Q_2), in parallel with current I_3 through resistors R_6 and R_7 and diode D_4. The resulting voltage drop across R_6 is sensed by IC_1. When the total forward current I_1 reaches a threshold value, the comparator toggles on (output high), aided by regenerative feedback through R_4. This turns Q_2 on hard, bypassing parasitic diode D_3 because Q_2 has a smaller resistance when conducting. Q_2 then conducts the main load current during the remainder of the half cycle.



The **Synchronous Half-Wave Rectifier** includes active circuits to attain a low forward voltage drop and, consequently, high rectification efficiency.

As the voltage drops to a low value toward the end of the forward half cycle, I_1 falls below the threshold and IC_1 turns off, again aided by regenerative feedback through R_4. This turns off Q_2. Both turnon and turnoff thresholds can be set at desired values by the appropriate choices of resistors R_2 through R_7.

Tests of a "breadboard" version of the circuit made of discrete components indicated that very high rectification efficiency is attainable. If fabricated as a monolithic assembly, the circuit should be at least as efficient as the "breadboard" version.

This work was done by Wally E. Rippel of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 15 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 14]. Refer to NPO-17220.

Field-Sequential Color Converter

Size, weight, and power consumption are reduced.

Lyndon B. Johnson Space Center, Houston, Texas

An electronic conversion circuit enables the display of signals from a field-sequential color-television camera on a color video camera. Designed for incorporation into a color-television monitor on the Space Shuttle, the circuit weighs less, takes up less space, and consumes less power than the previous conversion equipment, which had to remain on the ground. The circuit (see figure), which incorporates state-of-the-art memory devices, could also be used in terrestrial stationary or portable closed-circuit television systems.

The field-sequential technique of encoding color video signals reduces the size, weight, and power consumption of a video camera by requiring only one image sensor instead of the usual three. A wheel in front of the camera lens holds a red, a green, and a blue filter and turns in synchronism with the video-field rate to image the red, green, and blue components onto the image sensor during successive video fields. Each of the fields in the resulting video signal contains the corresponding single color component. For display on a color video monitor, this signal must be converted to a standard color video signal that contains all three colors simultaneously.

The first stage of the converter performs the balanced-to-unbalanced conversion, amplification, and buffering of the input video signal. One of the U_3 dual voltage comparators provides the composite synchronization signal, on which two phase-locked loops (PLL's) are locked. One PLL locks a 14.318-MHz oscillator to the horizontal-line rate and is used to provide the majority of the timing of the circuit. The

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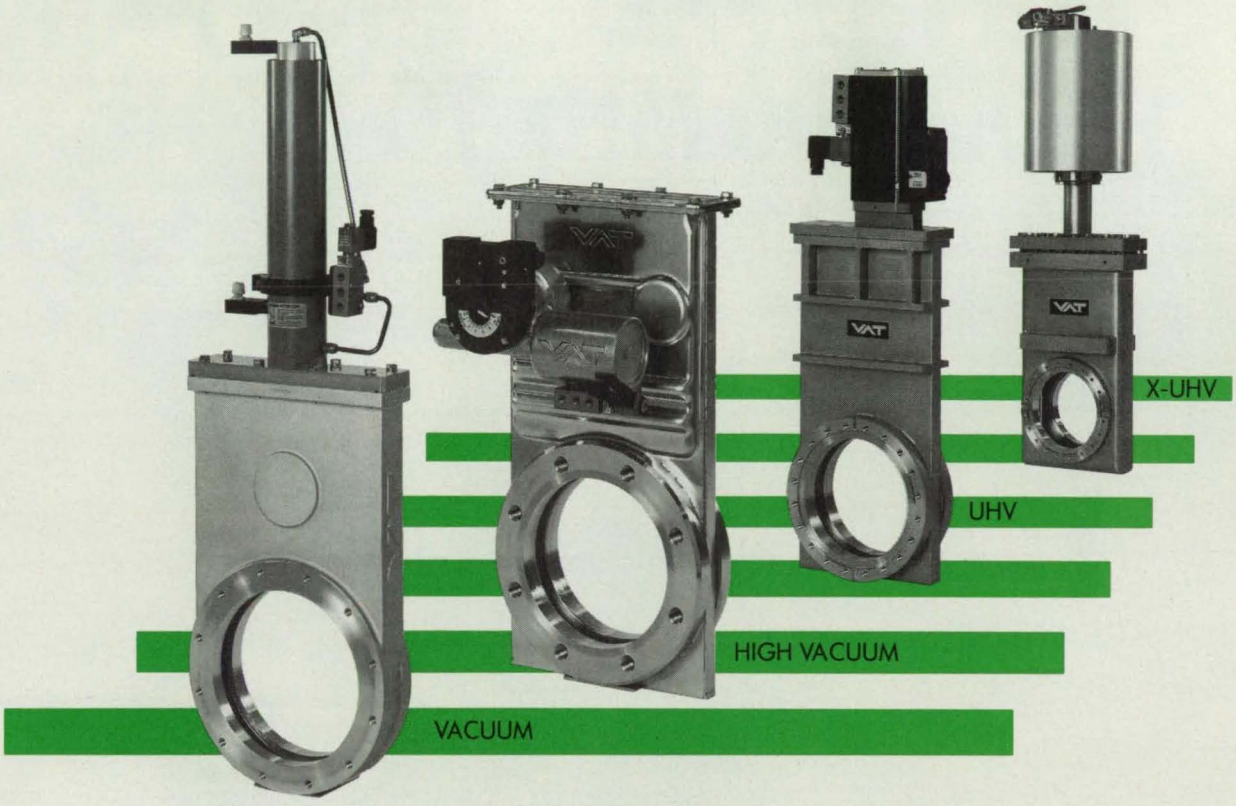

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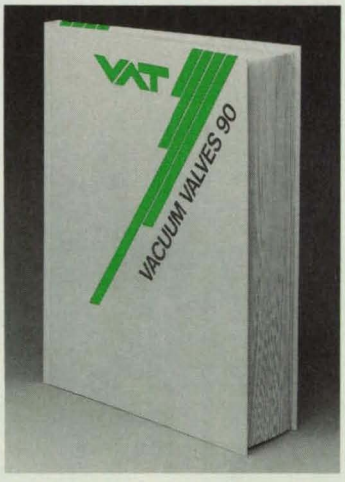

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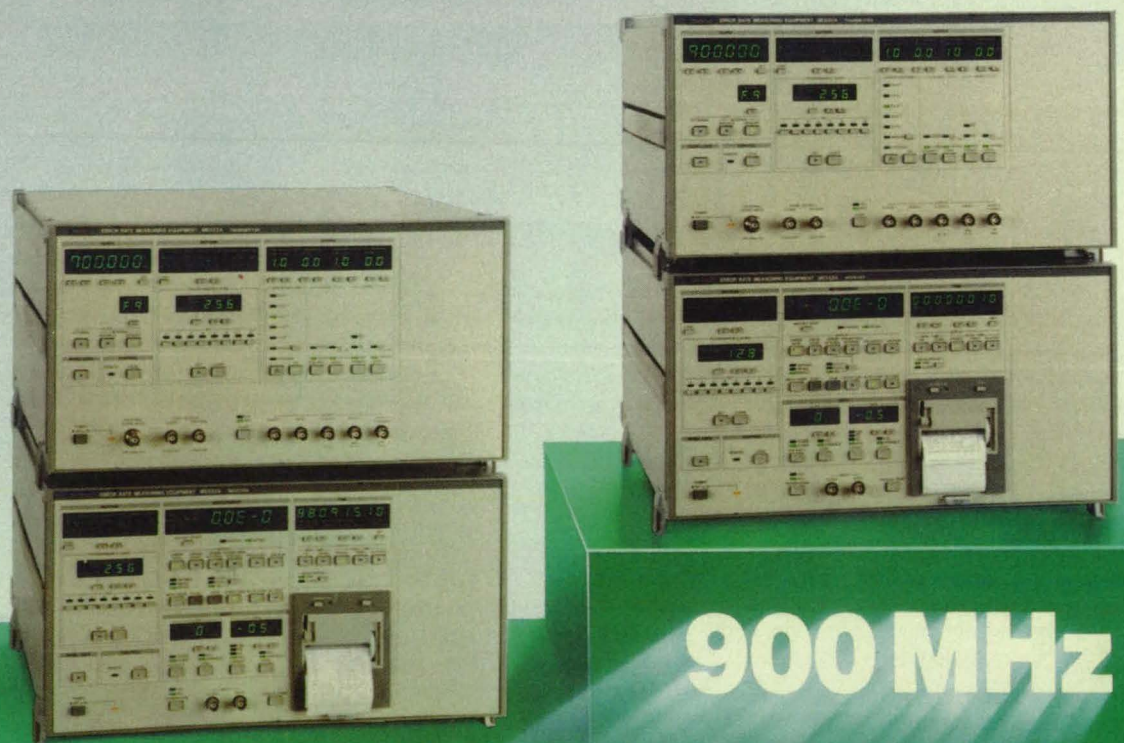

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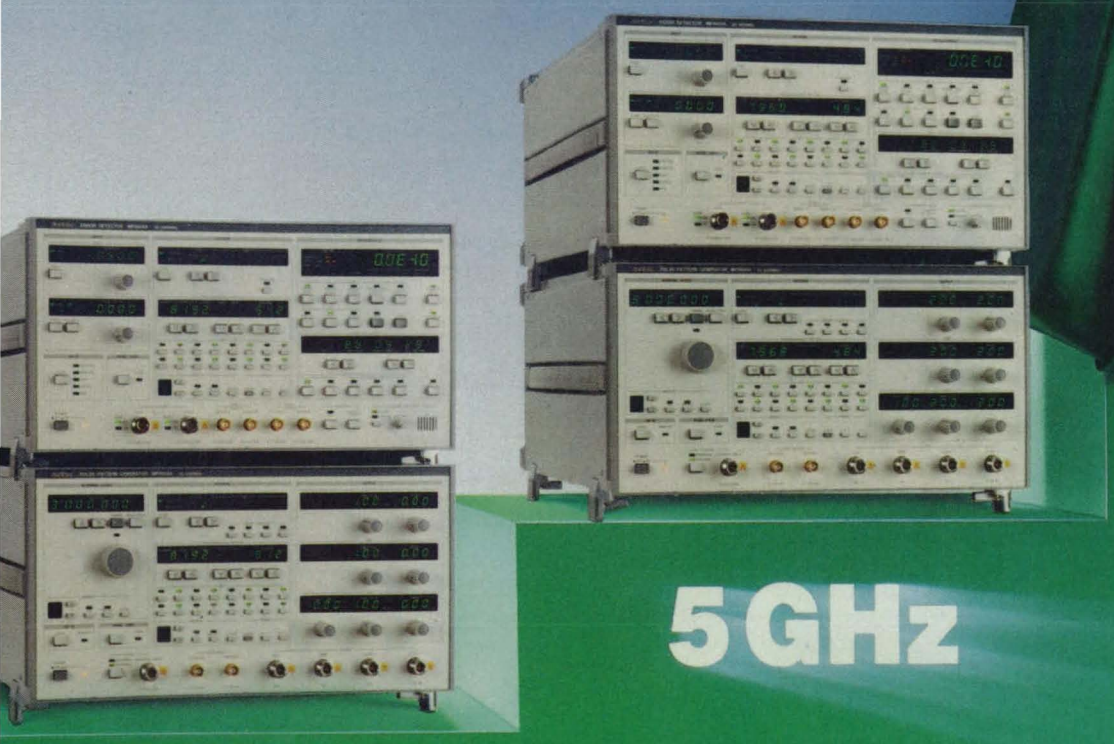

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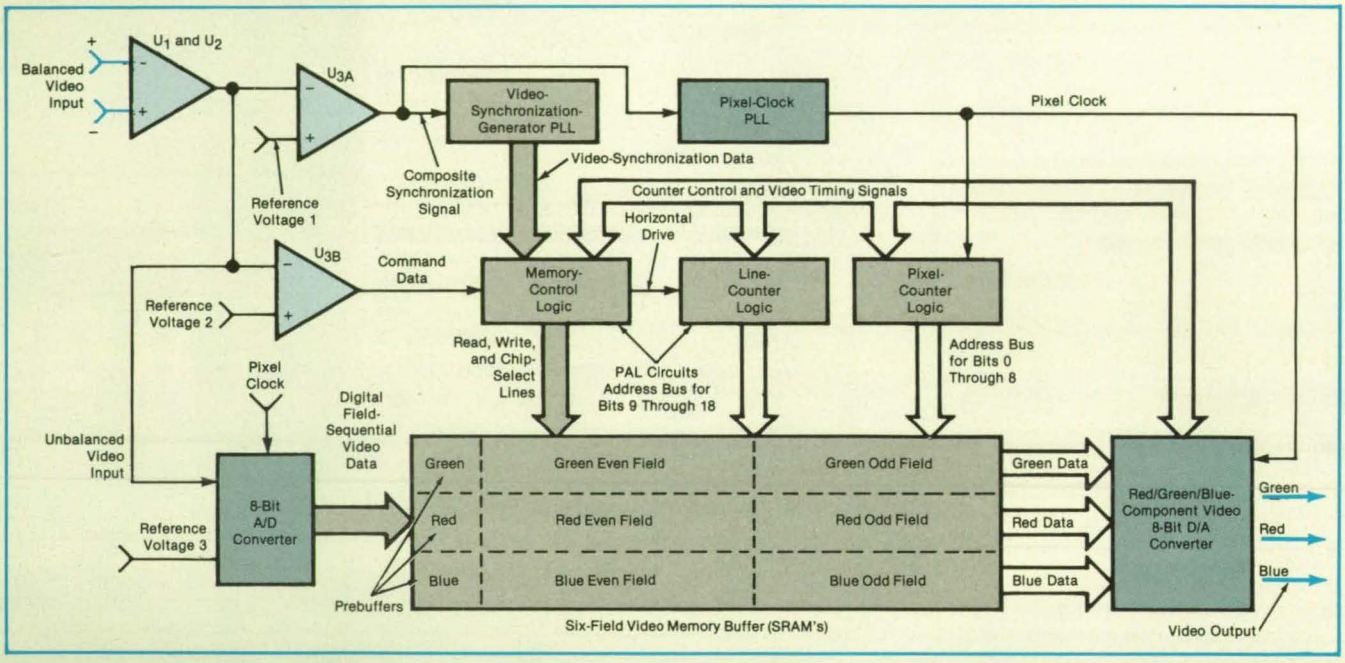
second PLL provides the pixel clock, which has an oscillator selected to give approximately 512 sampling pixels along each active video line. This signal provides analog-to-digital (A/D) and digital-to-analog (D/A) conversion sampling and line-address-counter clocking.

Most of the signals required for subsequent timing and logic control are provided by a video-synchronization generator locked to the incoming video signal by the 14.318-MHz PLL. An associated logic circuit maintains the even/odd field status and vertical-interval status. A 9-bit horizontal-line-pixel counter is built into the left programmable-array logic (PAL) circuit, which provides the lower bits of static random-access-memory (SRAM) addresses. The right PAL circuit contains an 8-bit counter that counts the video-line number.

The left PAL uses the pixel-counter data to derive the position in the line of a green-field-synchronization signal. This signal is encoded on line 18 of every third video field and indicates the start of a field of green-color information. This command is stripped off the video data by the second voltage comparator in U_3. The left PAL provides the line-18 location, which is logically combined with green-field synchronization data and position to provide a color-field-reset signal. This signal is used as a field-counter reset, indicating the start of a green field of data. The signals for the green, red, and blue field lines are then processed into signals that control the SRAM's.

Each of the six SRAM's serves as a video-field buffer. Six video fields are required to align the three color components with their even and odd video fields. Three circuits act as "prebuffers" by separating the three color components of the output of the A/D converter. New data from the current incoming field are written into either the even- or the odd-field memory. Data for the other two color components are read from the respective even- or odd-field memory. The three color components of digital data are sent to the D/A converter, which produces an RS-170 standard output for display by a red/green/blue color monitor.

This work was done by Victor J. Studer of **Johnson Space Center**. *For further information, Circle 88 on the TSP Request Card.*
MSC-21346



The **Field-Sequential Color Converter** processes field-sequential color video signals into standard video signals that can be used by a color video monitor.

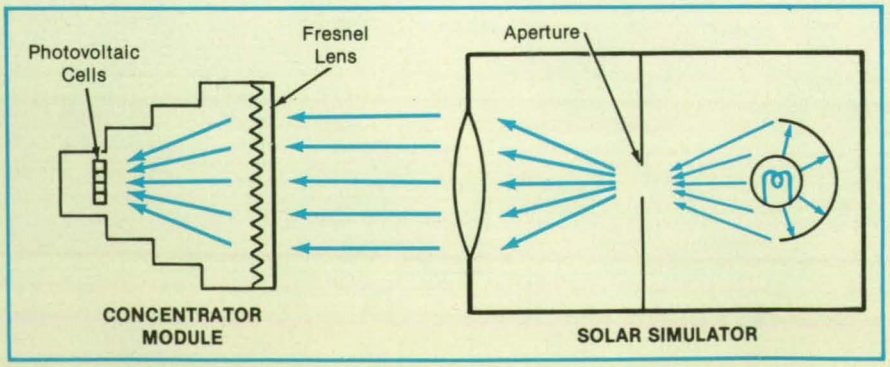
Hotspot Endurance of Solar-Cell Modules

A procedure for evaluating modules for use with concentrators is now available.

NASA's Jet Propulsion Laboratory, Pasadena, California

A procedure for testing modules of photovoltaic cells to be used with solar concentrators determines their ability to endure hotspots. Although procedures for testing flat-plate solar-cell modules have been available for some time, the new procedure is the first for concentrator modules.

A hotspot occurs in a photovoltaic cell when the current in a module of series-connected cells that contains the cell in question exceeds the short-circuit current of that cell. This condition forces the cell into reverse bias, increasing its power dissipation and raising its temperature. Hotspots can be created by cracks or shadow-



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Circle Reader Action No. 364

ing of cells in normal service, even in highly reliable arrays. It is therefore important to ensure that a hotspot does not propagate to other cells or present electrical hazards.

The procedure begins with the selection of three cells in a module: one that has the highest shunt resistance, one that has nearly average shunt resistance, and one that has the lowest shunt resistance. Each of the three cells is then connected to a separate power supply in such a way that the heat-transfer characteristics of the cells and the hotspot endurance are disrupted as little as possible.

The next step is to select the hotspot test level; that is, the level of heating that will stress the module as severely as it would be stressed by a hotspot during use. The principal test parameters include the reverse voltage, the ambient temperature, and, for cells that have reverse-breakdown voltages higher than the maximum available reverse voltages (those with generally high shunt resistances), the overall irradiance. Cells with breakdown voltages less than the available reverse voltages (those with generally low shunt resistances) tend to develop hotspots when shaded.

An infrared lamp heats the heat sink of the module to simulate the ambient temperature. Power is applied to the test cells. A solar simulator (see figure) illuminates the appropriate cells, and the cells to be shadowed are tested in ordinary laboratory light. A timer turns the power supplies, the infrared lamp, and the solar simulator on and off. The "on" time is 1 h; the "off" time is long enough to allow the cell to cool to within 10 °C of the ambient air temperature. The timer repeats the cycle until 100 h of "on" time have been accumulated.

The module and test cells are inspected visually at 24-h intervals during the test and again when the test is completed. The inspector looks for evidence of degradation, including cracking, delamination, outgassing or blistering of encapsulants, and melted solder. After the test, the electrical characteristics of the module are measured for comparison with the pretest characteristics.

This work was done by C. C. Gonzalez, R. S. Sugimura, and R. G. Ross, Jr., of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 157 on the TSP Request Card. NPO-17305*

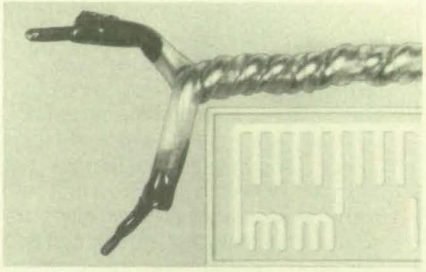
Twisted Pair of Insulated Wires Senses Moisture

Sensitivity to low levels of moisture is increased.

NASA's Jet Propulsion Laboratory, Pasadena, California

The sensitivity of an electronic moisture sensor to low levels of moisture is increased by a new electrode configuration. Instead of attempting to bond porous, flexible electrodes to metal films, the designers of the new sensor use plated solid wires as electrodes. The wires are encapsulated in tubes of a polysulfonated polymer and twisted together in a tight spiral (see figure).

The moisture-sensing circuit was described in "Low-Cost Humidity Sensor" (NPO-16544), *NASA Tech Briefs*, Volume 9, No. 4 (Winter 1985), page 55. The new twisted pair of wires takes the place of a flat-plate capacitor in that circuit. The capacitance varies with the humidity, thereby varying the frequency of the oscillator, which is read as an indication of the humidity.



Twisted-Wire Electrodes are sheathed with a polymer dielectric. The bare wire tips are for monitoring purposes.

The twisted-pair configuration allows for the thermal expansion and contraction of the polymer while maintaining a nearly constant area of contact between the polymer and the wires. The bare electrode wires are allowed to protrude at the ends of the twisted pair. These bare extensions enable the monitoring of the transducer and serve as convenient points for the introduction of forced signals to test the transducer.

This work was done by Eric G. Laue and James B. Stephens of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 137 on the TSP Request Card.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

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Refer to NPO-17111, volume and number of this NASA Tech Briefs *issue, and the page number.*

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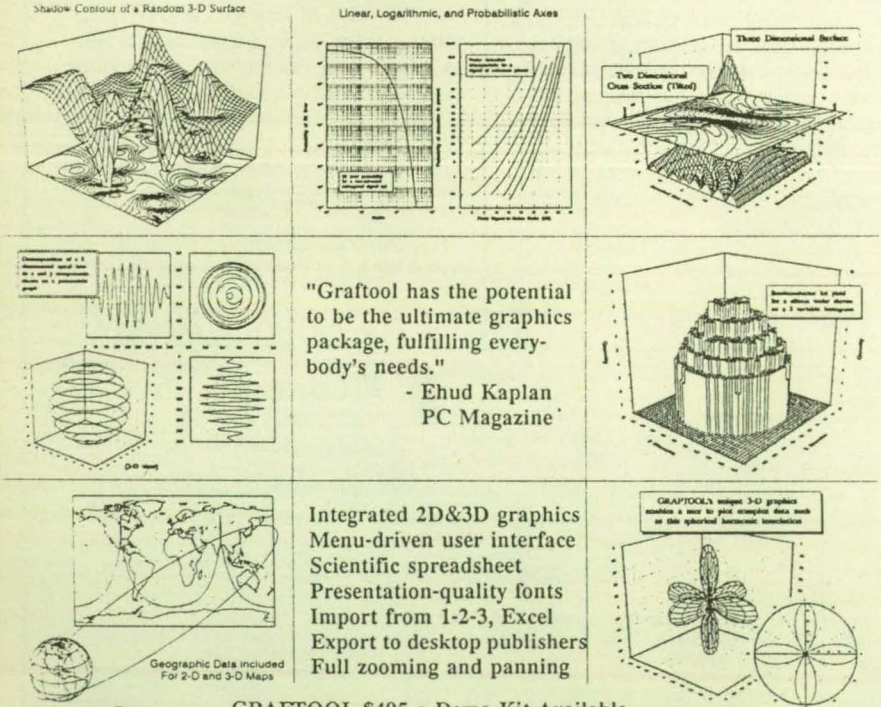

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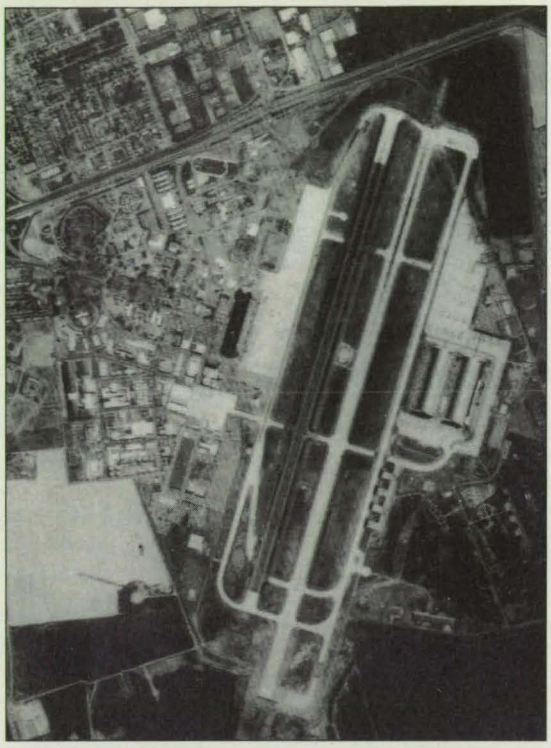

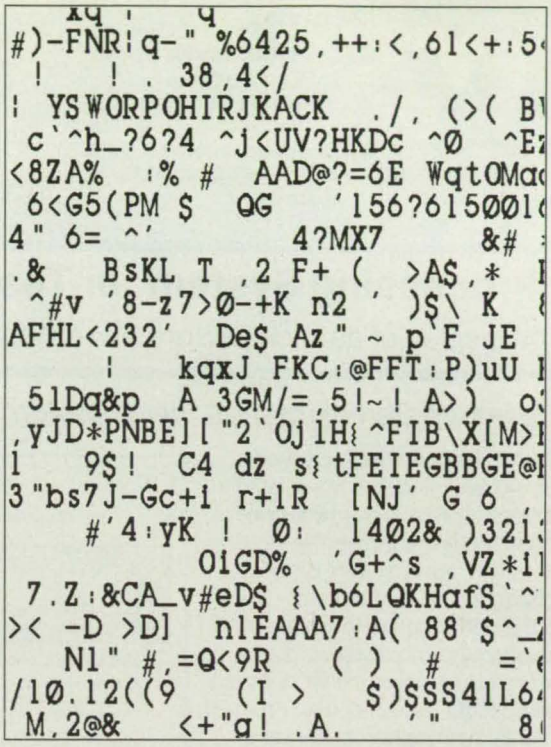

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Right. Alphanumeric data presented in a random format.

Circle Reader Action No. 512

Electronic Systems

Hardware Techniques, and Processes

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Data-Processing System for Test Airplane

Real-time display of data on performance supports decisions regarding maneuvers.

Ames Research Center, Moffett Field, California

The X-29A advanced-technology-demonstrator airplane and the associated ground control station have been equipped with electronic equipment (see Figure 1) for the acquisition, transmission, processing, and display (all in real time) of data relating to the performance in flight. The data-processing system calculates the in-flight measured drag polar, the lift curve, and aircraft-specific excess power. From these elements, many other measures of performance can be computed and analyzed.

Traditionally, data on the performances of airplanes during test flights have been calculated and analyzed after the flights. Such postflight analysis often reveals errors and other inadequacies in the data that require the repetition of a flight test. By enabling real-time evaluation of flight-test maneuvering techniques and the quality of data, the new data-processing system makes it possible to repeat a maneuver immediately, while flight-test conditions are still suitable.

The data-acquisition subsystem (see Figure 2) aboard the airplane uses both pulse code modulation (PCM) and frequency modulation (FM) for transmission of sensor data on the operation of the engine, the performance of the airplane, and the conditions in the atmosphere. No data are recorded on the aircraft. The 10-bit PCM system transmits at rates that vary from 25 to 400 samples per second, depending on the desired frequency range to be covered. The digital data are processed by five PCM units, and an interleaver device merges the stream of data along with the output from the bus of the flight-control computer. The data are telemetered as an uncalibrated serial PCM stream.

The constant-bandwidth FM system transmits high-response acceleration and vibration data. This FM signal is merged with the rest of the digital data from the interleaver and telemetered to the ground along with the pilot's voice signals. About 700 measured data parameters are telemetered to the ground for recording, analysis in real time, and monitoring in the control room. The set of data parameters includes measurements for structural loads, structural dynamics, flight controls, stability and control, aircraft subsystems, propulsion and performance, wing deflections, buffet, and external pressure distributions.

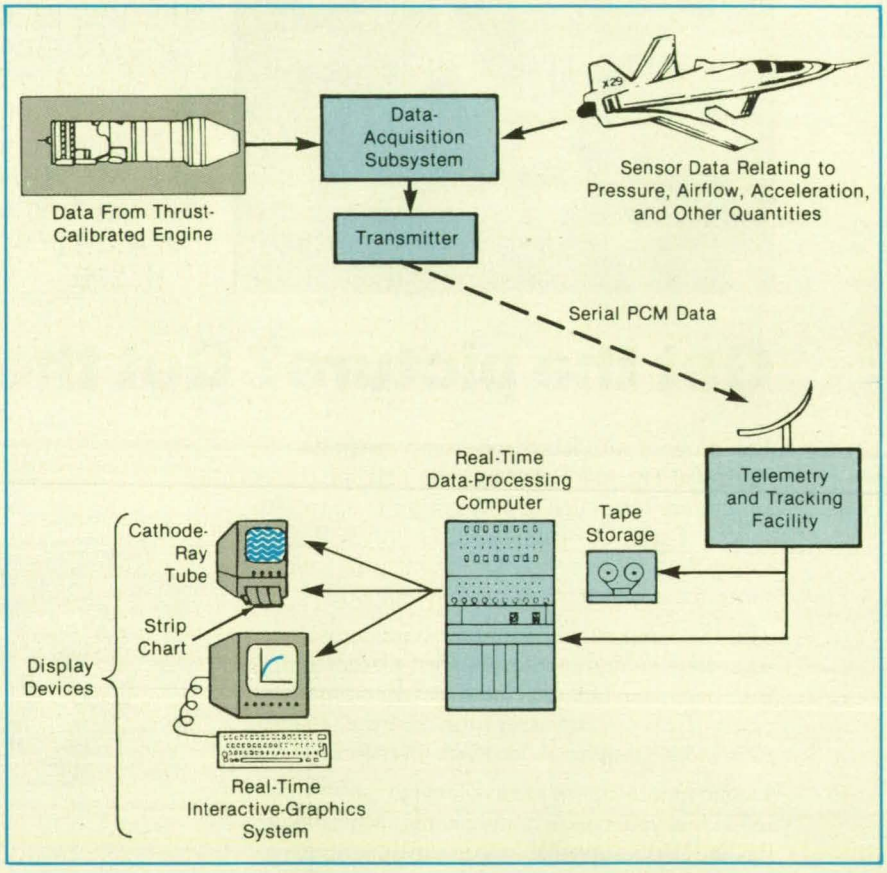

Figure 1. **Data From Sensors Aboard the Airplane** are transmitted to the control station on the ground for immediate processing and display.

An essential element of the software component of the system is the real-time, in-flight net-thrust algorithm, which is based on the simplified net-thrust method. The only inputs required by this algorithm are the free-stream static air pressure, the total temperature at the turbine-rotor discharge, the calculated true velocity, and the gas pressures measured at three locations in the afterburner duct of the engine. The algorithm computes the gross thrust on the basis of a one-dimensional approximation of the flow in the afterburner and exhaust nozzle. Using additional inputs from the air-data subsystem, the algorithm also calculates the ram drag and the net thrust. The uncertainty in the real-time coefficient of drag has been estimated to be about 3 percent.

This work was done by R. J. Ray, J. W. Hicks, and R. I. Alexander of **Ames Research Center**. *Further information may be found in NASA TM-100432 [N88-21151], "Development of a Real-Time Aeroper-*

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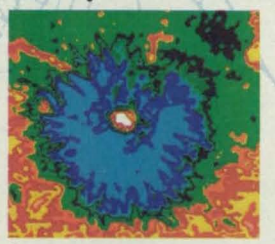

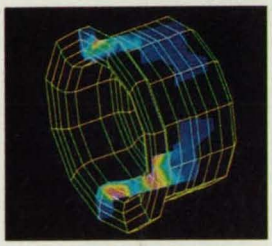

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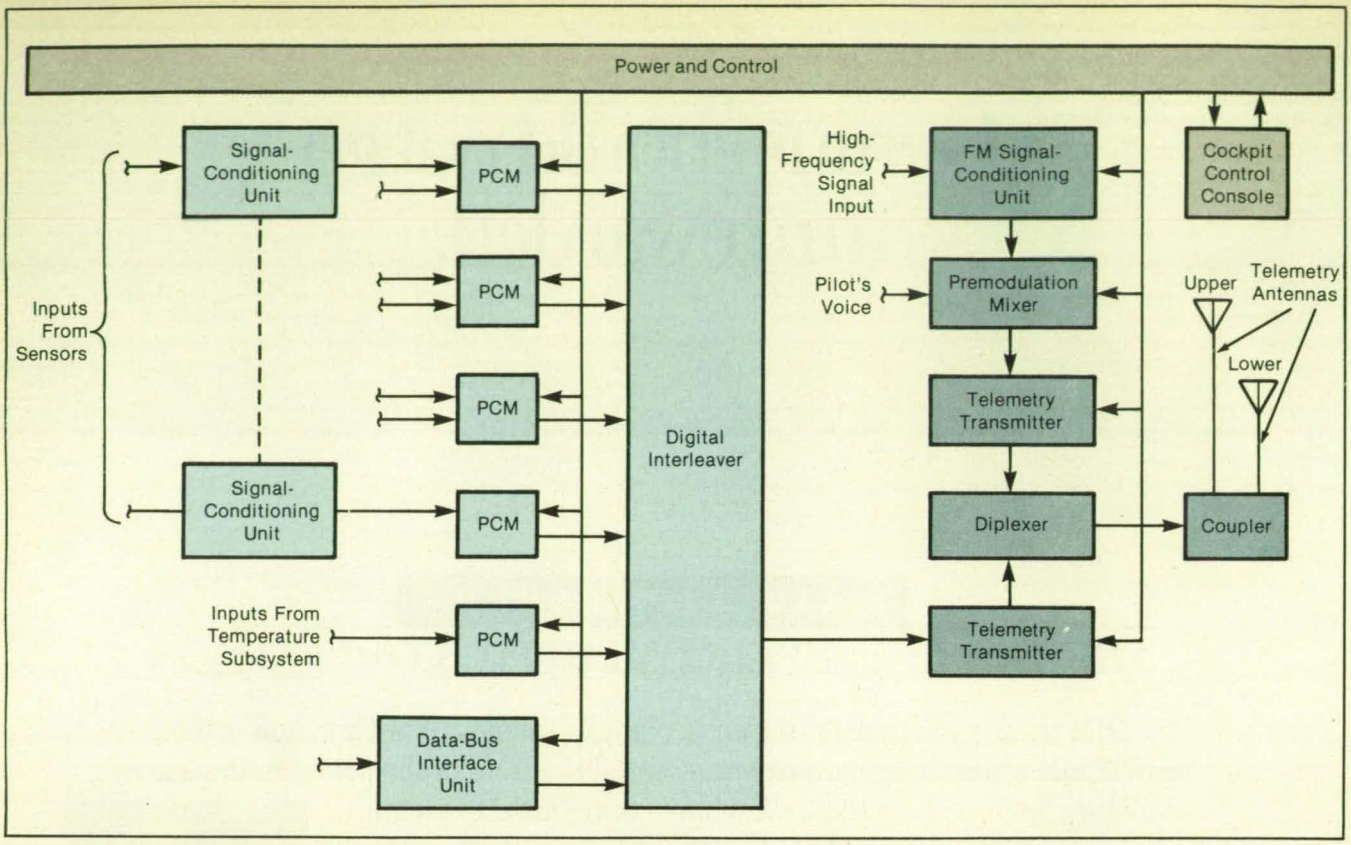

Figure 2. The **Data-Acquisition and -Transmission** subsystem of Figure 1 is shown here in more detail.

formance Analysis Technique for the X-29A Advanced Technology Demonstrator."

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Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center [see page 14]. Refer to ARC-12212

Adjusting Surfaces of Large Antenna Reflectors

A new approach is more effective than the traditional rms-surface-distortion approach.

Langley Research Center, Hampton, Virginia

In the design and operation of large antenna reflectors for use in outer space, a principal issue is the precise control of the shape of the reflector surface required to guarantee satisfactory electromagnetic (EM) performance. While the need to control the shape is clear, the implementation is a subject of current research. In the past, the link between the loss of performance of an antenna and deformation of the structure of the antenna has been based on classical formulas in which the loss is related to the root-mean-square (rms) value of the distortion of the surface. Although a reduction in this rms value has a significant effect on the gain, it does not necessarily improve such other performance parameters as the shape or pointing direction of the beam and the levels and distribution of side lobes, which depend upon the details of the distortion throughout the surface of the reflector.

There is a new optimization procedure for control of the shape of the reflector of a large space antenna (LSA). The main feature that distinguishes this procedure from previous ones is that the shape-controlling mathematical mechanism is driven by the need to satisfy explicit EM design requirements rather than implicit limits on the rms accuracy of the surface.

The procedure uses standard finite-element structural analysis, aperture-integration EM analysis, and constrained optimization techniques to predict a set of actuator inputs that will improve the performance of an antenna while minimizing the applied control effort. The procedure was tested for a 55-meter tetrahedral-truss antenna designed for a microwave-radiometer mission. A radiometer design is an attractive test case because remote sensing is a driving force behind NASA's interest in LSA systems and because the constraints on EM performance are both critical and difficult to achieve.

In this test case, the shape of the surface of the radiometer is controlled by a set of actuators that can lengthen or shorten individual members of the backup structure. The optimization procedure must select a set of actuator inputs that smooths the surface of the reflector enough to satisfy criteria for EM performance while minimizing the total actuator effort. The results indicate that this procedure produces a much better set of actuator inputs than does the traditional approach based on constraints on rms distortion of the surface.

The procedure is applicable to a wide variety of LSA concepts. The only assumption is that the original distortion of the surface is known precisely at a discrete number of locations and that the change in this distortion for a prescribed change in actuator inputs can be predicted. The quality of the optimum design can be improved even further by refining the finite-element model of the structure, by increasing the number of discrete points used to describe the surface of the reflector, and by increasing the accuracy of calculations of EM performance.

This work was done by Sharon L. Padula, Howard M. Adelman, and Marion

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C. Bailey of **Langley Research Center** *and Raphael T. Hoftka of Virginia Polytechnic Institute and State University. For further information, Circle 64 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 14]. Refer to LAR-13851.

General-Purpose Electronic System Tests Aircraft

Versatile digital equipment supports research, development, and maintenance.

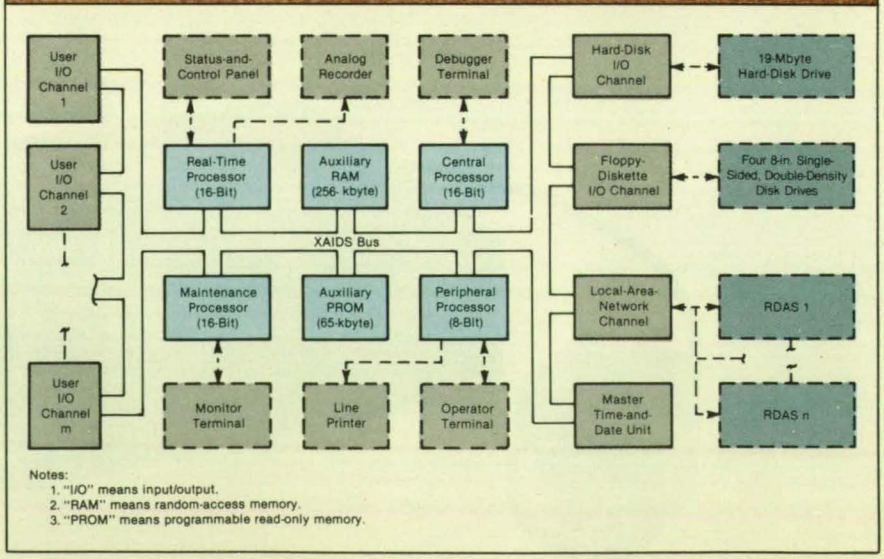
Ames Research Center, Moffett Field, California

The extended aircraft interrogation and display system (XAIDS) is a general-purpose assembly of digital electronic equipment on the ground for the testing of digital electronic systems on advanced aircraft. The XAIDS is the enhanced, second-generation version of a prior system developed to support the integration of digital flight systems, the verification and validation of software, preflight and postflight testing, and maintenance. To perform the tasks now accomplished in a unified manner by the XAIDS, it was previously necessary to use special-purpose ground support equipment for each project and, therefore, to build and maintain an inventory of many different types of equipment of varying capability.

The system (see figure) has many advanced features, including multiple 16-bit microprocessors, pipeline data-flow architecture, advanced operating system, and resident software-development tools. The basic collection of software includes programs for handling many types of data and for displays in various formats. The user can easily extend this basic software library. Hardware and software interfaces to subsystems provided by the user have been designed for flexibility in configuration to meet the user's requirements.

An auxiliary remote data-acquisition subsystem (RDAS) serves as an input/output interface that can be located near the system to be tested. An RDAS is intended for use where direct cabling to the XAIDS would be too complicated or vulnerable to electromagnetic interference. An RDAS can be located as far as 5,000 ft (1.5 km) from the XAIDS, with control and data signals flowing at a 1-MHz rate over a local-area network that uses a single RG-59/U coaxial cable 3/16 in. (4.8 mm) in diameter.

The XAIDS has contributed greatly to the work on the X-29A forward-swept-wing airplane. It has centralized the operators' activities at a single work station, providing both analysis of telemetry data and control of the flight-computer test set. Software has been developed to enable operators to overlay the memory of the flight computer with test code and/or tables of data, so that test conditions can be altered and the telemetry stream can be remapped. In addition, several large modules of software have been incorporated to provide evalua-



The **Extended Aircraft Interrogation and Display System** is pipelined, multiprocessor, general-purpose digital electronic ground support equipment for the testing of digital flight systems.

tions of the performance of the flight-control system.

This work was done by Richard D. Glover of **Ames Research Center**. *Further information may be found in NASA TM-86740 [N87-16820], "Design and Initial Application of the Extended Aircraft Interrogation and Display System."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.

ARC-12148

Radar Polarimeter Measures Orientations of Retroreflectors

Polarization signatures of targets are to be compared with known signatures at known angles.

NASA's Jet Propulsion Laboratory, Pasadena, California

Experiments have demonstrated the use of radar polarimetry to measure the orientation of a retroreflective target, even though the target is much smaller than the resolution element of the radar. The technique is based on the comparison of the angular dependencies of the measured and theoretically derived polarization signatures of the target. In principle, the polarization signature could also be used to identify a target.

As the term implies, the polarization signature of a target is proportional to the radar scattering cross section of the target as a function of the angles of polarization of the illuminating and reflected radiation. The scattering properties of the target are conveniently summarized by the scattering matrix, S, which expresses the relation between the amplitudes r_h and r_v of signals reflected or received in horizontal or vertical polarization, respectively, and amplitudes t_H and t_V of signals transmitted in horizontal or vertical polarization, respectively.

Matrix S and the radar cross section, which is easily calculated from S, vary as the target is rotated about the radar line of sight or, equivalently, as the radar antenna is rotated around the line of sight and/or the radar polarization is varied. For example, the left side of Figure 1 shows theoretical radar cross sections for copolarized reflections (identical transmitting and receiving polarizations) from a rough surface, from a dihedral corner reflector, and from a trihedral corner reflector as functions of the orientation of the polarization ellipse and of the ellipticity angles. (Ellipticity angles of ±45° denote circular polarization, while 0° denotes linear polarization.)

The right side of Figure 1 shows the signatures of a dry lakebed and two corner reflectors mounted on it, as measured by an airborne radar. The tilt of the reflector showing the two-bounce response can be inferred by integrating the squared differences between the measured signatures and the calculated two-bounce signatures over all states of polarization and noting the tilt angle that would minimize the error (see Figure 2).

This work was done by H. A. Zebker and L. Norikane of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 20 on the TSP Request Card.*

NPO-17231

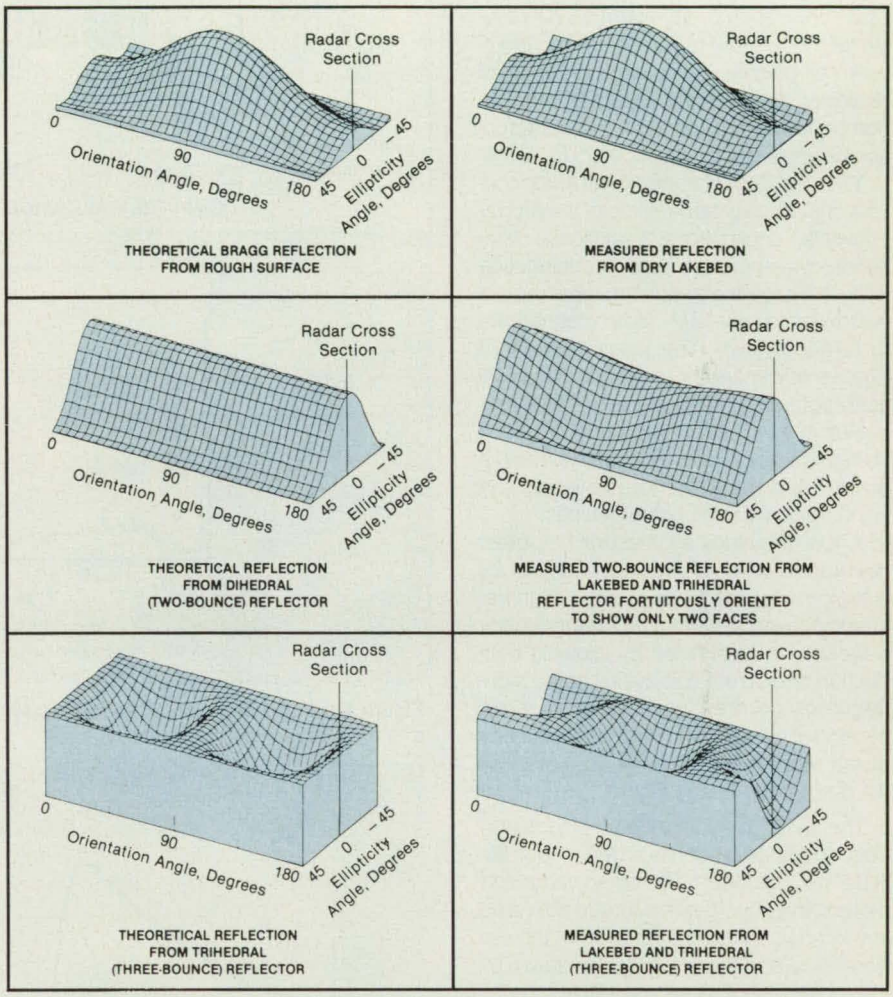


Figure 1. **Radar Cross Sections** were calculated theoretically and measured for three representative targets.

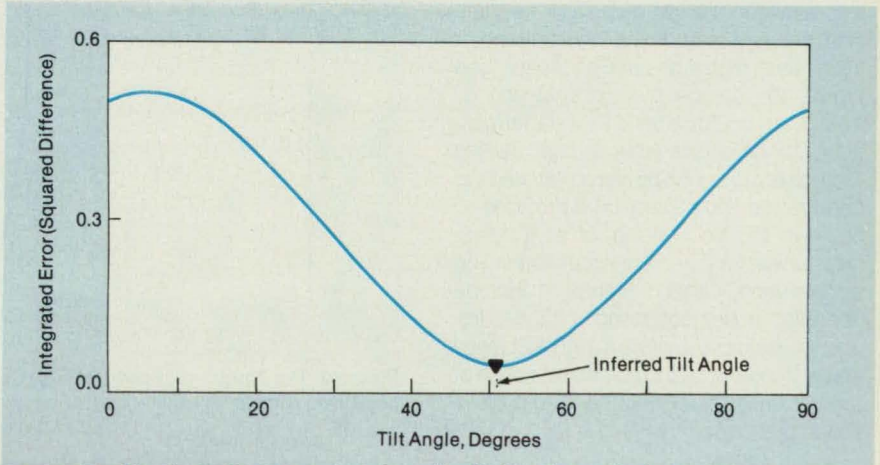


Figure 2. The **Tilt of a Reflector** can be inferred by finding the angle that minimizes a measure of the difference between theoretical and measured radar cross sections of the reflector.

Pulse-Population Modulation for Induction Machines

Low-frequency waveforms are synthesized as needed from a high-frequency power supply.

Lewis Research Center, Cleveland, Ohio

The power-distribution system for the proposed Space Station is a single-phase, 440-Vrms, 20-kHz system, with a regulated sinusoidal waveform. A single-phase power system minimizes the complexities of wiring, sensing, and control required in a multisource, redundantly-distributed-power system. The 20-kHz operating frequency was selected to be above the range of audibility, minimize the weight of reactive components, and yet allow the construction of single power stages of 25 to 30 kW.

With regulated voltages, most ac/dc conversions involve rather-simple transformer/rectifier applications. A sinusoidal distribution system, when used in conjunction with zero-crossing switching, represents a narrow-band source of electromagnetic interference (EMI). The present state of 20-kHz power technology includes computer controls of voltage and/or frequency, cables of low inductance, current-limiting protection of circuits, bidirectional flow of power, and motor/generator operation using standard induction machines.

A low-frequency synthesizer has been developed to provide a low-frequency waveform by synthesis from a high-frequency power system. The low-frequency waveform is assembled by allowing conduction of discrete half cycles of the high-frequency carrier. One advantage of this method of modulation is that the frequency of the synthesized wave is controlled by the pulse pattern (see Figure 1).

The ability to control the amplitude and frequency independently provides wide latitude for the operation of ac induction motors, inasmuch as the torque delivered at any shaft speed is a function of the slip frequency, and the power factor drawn by the motor at any given speed/load combination is a function of the terminal voltage.

In addition, by controlling the relationship between the slip and stator frequencies, one can operate the induction motor either as a motor or as a generator (see Figure 2). Such a bidirectional energy transducer could be used as a starter/generator for an engine wherein high starting torques are provided by high controlled slip frequencies and generation is provided by negative slip frequencies, or as a servomechanism for control of acceleration and deceleration. Other advantages include operation under controlled voltage-to-frequency ratios to maintain high-efficiency and high power factor, and no reflection of low-frequency noise into the 20-kHz distribution bus.

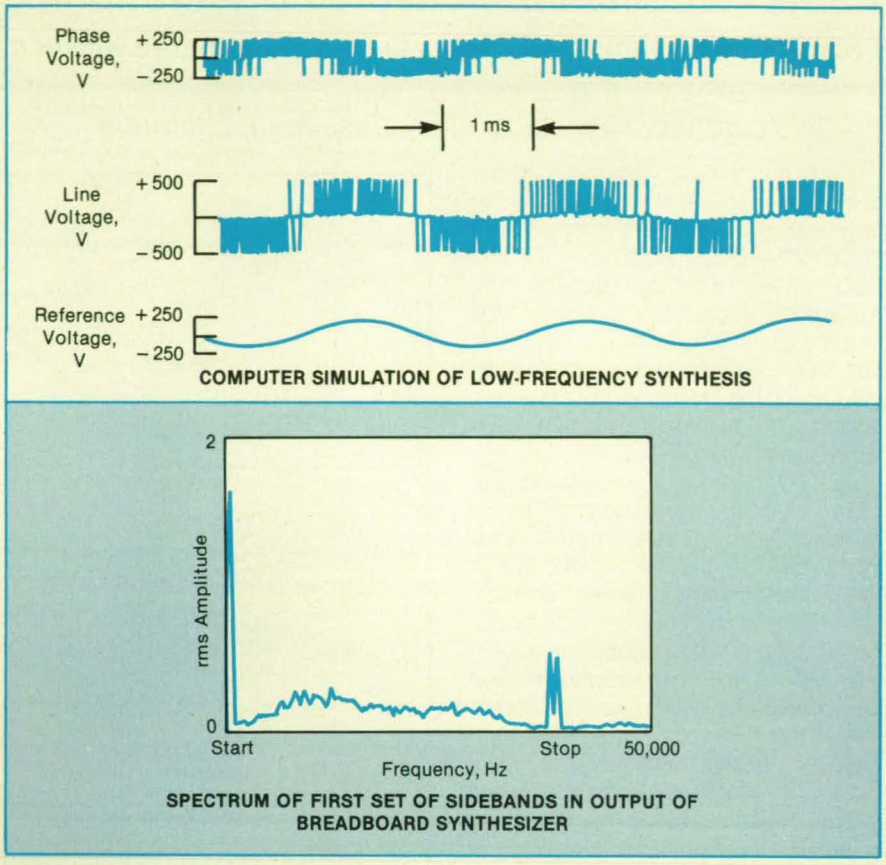


Figure 1. A **Low-Frequency Waveform** is synthesized from selected conduction half cycles of a high-frequency waveform.

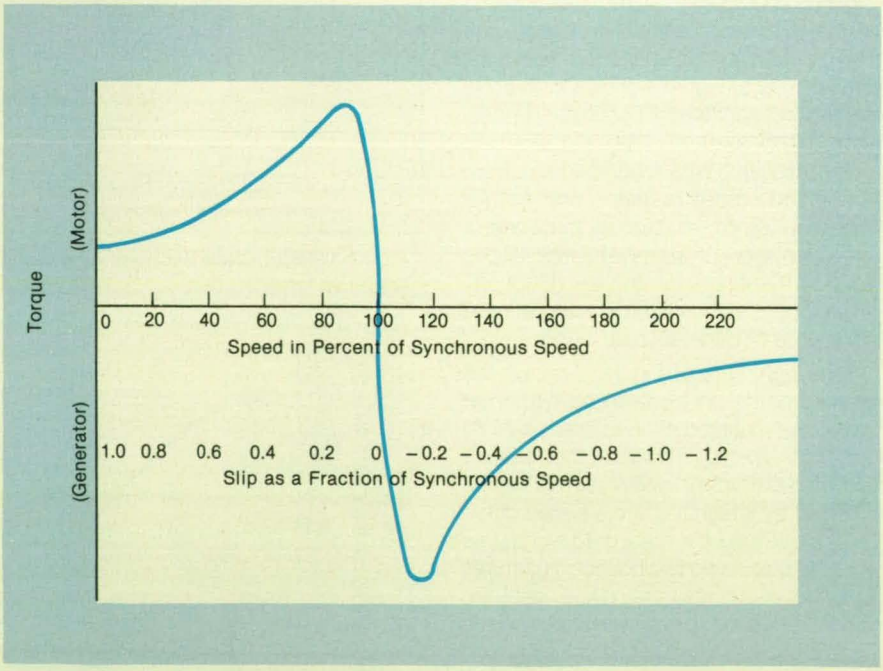


Figure 2. The **Torque-vs.-Speed (or Slip) Curve** of an induction machine has both positive and negative regions, signifying operation as either a motor or a generator.

This work was done by Irving G. Hansen of **Lewis Research Center**. *Further information may be found in:*

NASA TM-87346 [N86-31584], "Description of a 20 Kilohertz Power Distribution System," and

NASA TM-89925 [N87-22004], "EMC and Power Quality Standards for 20-kHz

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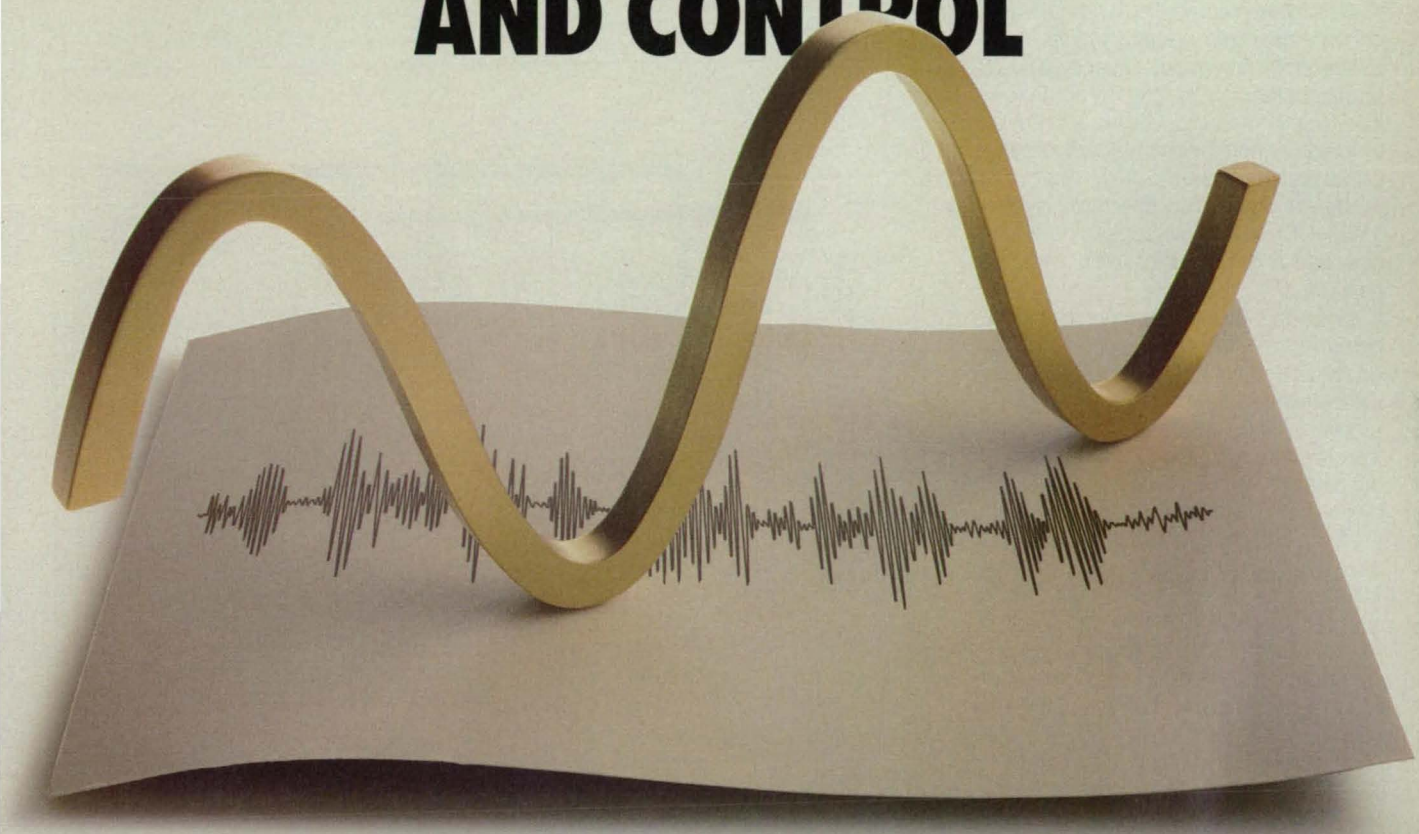

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Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Lewis Research Center [see page 14]. Refer to LEW-14669.

Balanced-Load Real-Time Multiprocessor System

Modularity and parallelism provide tolerance to faults and high throughput capacity.

NASA's Jet Propulsion Laboratory, Pasadena, California

A distributed computing system is tolerant of damage and temporary faults and offers a high throughput capacity and dynamic balancing of the computational load. This system, called MAX, is a network of interconnected computers. It is based on a distributed-data-flow execution model, a distributed operating system (HYPHOS), a multiple-access broadcast bus, and a point-to-point circuit-switched network.

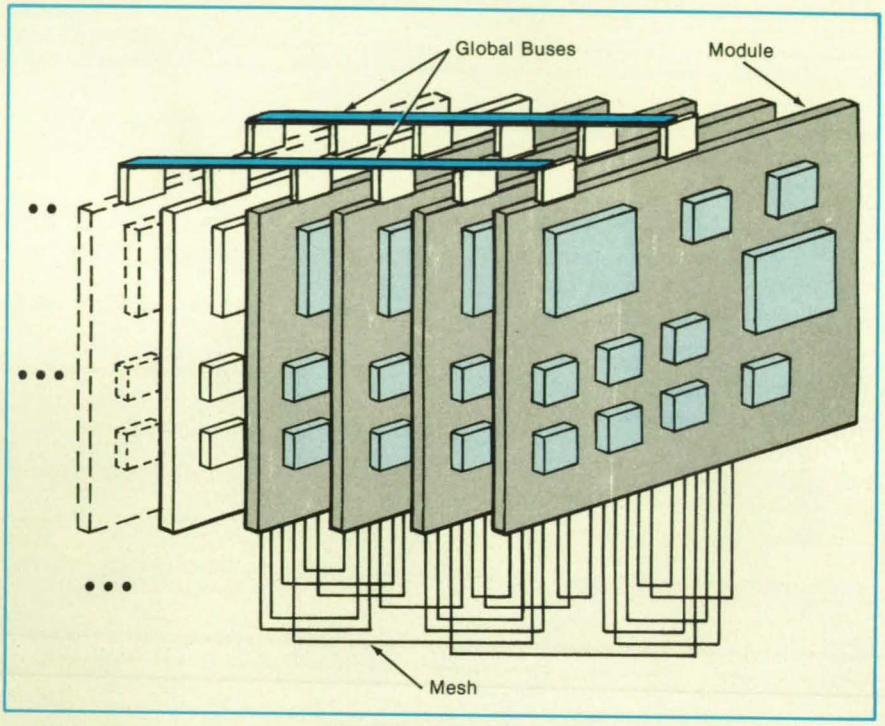
In the data-flow architecture, a program comprises independent functions. The execution of a function is made possible by the presence of the data required by the function. These data are encapsulated in tokens that identify the functions for which the data are intended. The use of the token by the function consumes the token, and the functions produce results in the form of new tokens. The tokens flowing between functions are automatically queued. There is no correspondence between a datum and its location in the memory.

A particular function becomes "fireable" — that is, ready for execution — as soon as it has received all of the necessary input tokens specified by its firing rule. Therefore, several functions may be fireable at any one moment. If the functions are distributed over the processing units of the system, all fireable functions are executed in parallel at the earliest opportunity. A large assortment of firing rules is provided to support real-time programming and fault tolerance.

The data flow smoothly handles transient workloads that arise from asynchronous inputs and variable computing times. It offers parallel paths for simultaneous execution and allows processing of consecutive inputs to overlap.

The data-flow system is a low-resolution one; its structures and functions, written in a high-order language, are more complex than those of high-resolution systems. Although a low-resolution system extracts less concurrent operation from an algorithm, such a system also involves less scheduling and synchronization.

The data-flow token is the basic unit for most MAX system functions. Software modularity, communication, concurrency, memory partitioning, and data comparison for fault detection are all performed at the token level. Full exploitation of this unifying mechanism beyond any previous system is the essence of the MAX design.



A **MAX Cluster** consists of a group of modules — each a semiautonomous computer. The modules are connected to each other and to other clusters by a global bus and a circuit-switched communication mesh.

Overall, the MAX system consists of clusters of computer modules connected by global buses and the switched communication mesh (see figure). Each module is a self-contained computer that operates autonomously, using the HYPHOS distributed operating system.

Special-purpose boards can be attached to a module to enhance its capability, or such devices can be incorporated into the communication mesh.

The HYPHOS operating system uses special features of the global buses for software synchronization. The communication mesh transports the data between the modules.

There is no central controller in the system. Instead, the HYPHOS operating system in each module acts in concert with the others, to support multitasking, communication, and related functions. A graph-execution manager schedules data-flow tasks within a module.

A module is implemented on a single board with dual 32-bit microprocessors — one primarily for HYPHOS functions and the other for application-software functions. A module also contains fast floating-point hardware and intelligent multiple-channel direct-memory-access coprocessors. There are also six 10-Mb/s communication ports, priority interrupts, and programmable timers. System software resides in a read-only memory. At least 128 kilobytes of random-access memory (RAM) are available in each module, and connections are provided for external RAM and memory-mapped input/output.

This work was done by Robert D. Rasmussen, Robert M. Manning, Blair F. Lewis, Gary S. Bolotin, and Richard S. Ward of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 3 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 14]. Refer to NPO-17185.

Books and Reports

These reports, studies, handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Assessment of Digital Control for Helicopters

Digital flight controls are essential for high performance in advanced military rotorcraft.

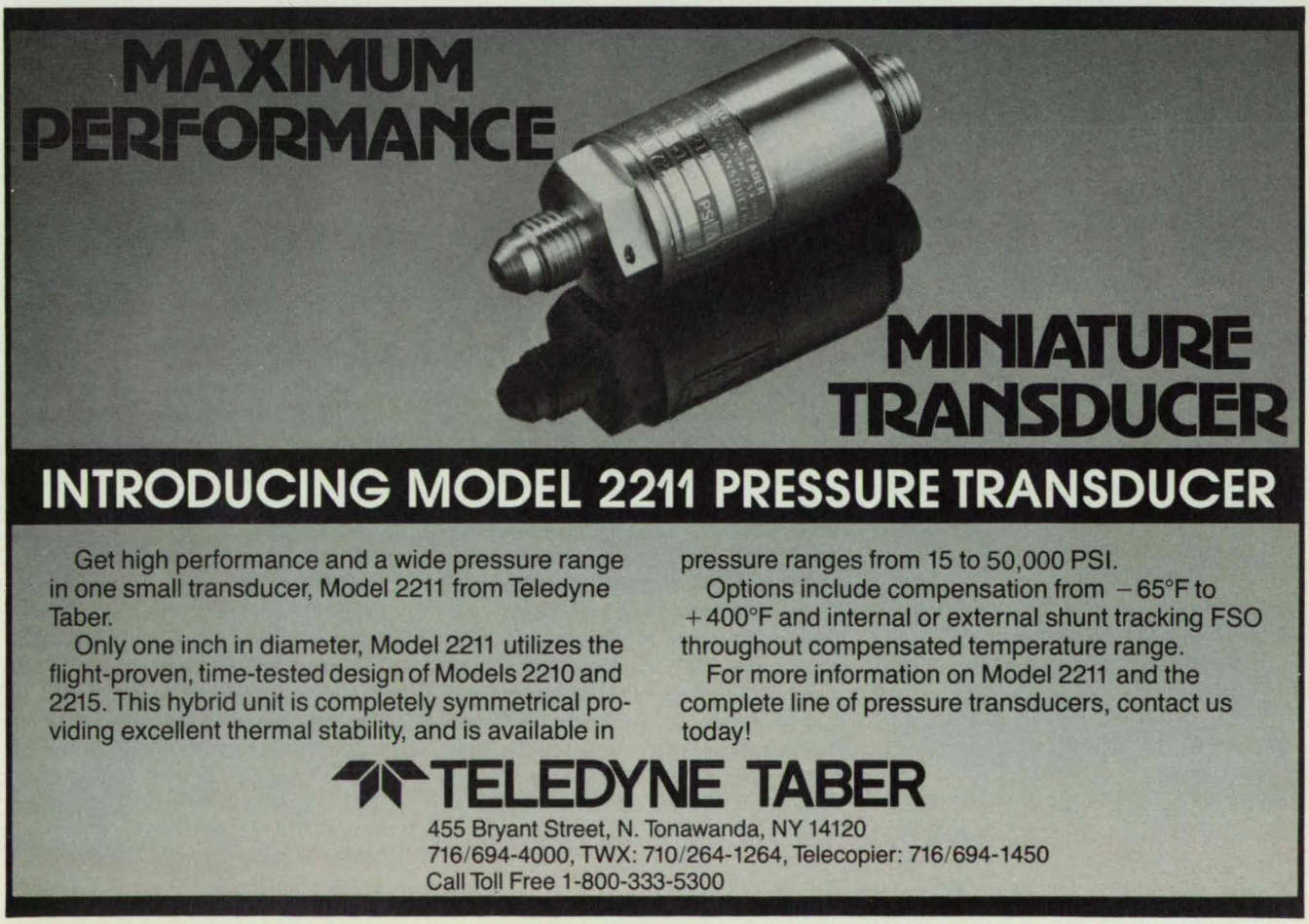
A report provides an assessment of digital electronic flight-control technology for advanced helicopters intended for use in combat. The overall goal is to describe practical methods for the analysis of high-gain digital control systems, with a view toward reducing the dependence on the flight tests and postdesign modifications that are commonplace in the development of first-generation digital systems for airplanes.

Digital flight-control systems are critical to the success of the mission of advanced combat rotorcraft. Single-pilot and nap-of-the-Earth operations require handling qualities that minimize the involvement of the pilot in the basic tasks of stabilization. Full-authority, high-frequency, high-gain, multimode, multiply redundant digital flight-control systems are necessary to satisfy these requirements. The work described in this report is part of the effort to make the transition from the current low-authority, low-bandwidth flight-control technology to the technology that will satisfy these requirements.

The report reviews the state of the art of high-bandwidth digital flight-control systems for airplanes, with emphasis on topics of concern for the development of such systems for modern combat helicopters. Important aspects of the design and analysis of high-gain digital systems are illustrated by use of results from a detailed study of a current rotorcraft system. Frequency-domain methods for design and analysis are stressed as being essential for the practical implementation of high-gain control systems for rotorcraft. There is a description of approximate and exact methods for prediction of the behaviors of digital flight-control systems.

The following are among the conclusions reached during the study:

- The attainable bandwidth of high-gain flight-control systems has consistently been overestimated in design studies; this overestimation is generally not exposed until the equipment is tested in flight.
- Delays in responses to commands have historically been principal causes of deficiencies in the handling qualities of high-bandwidth control systems. Such deficiencies are generally not exposed in piloted simulations conducted during the preliminary design phase. Therefore, careful design and analysis are needed to anticipate and minimize unnecessarily long delays.
- Rotorcraft are especially susceptible to biodynamic interference effects because of high levels of rotor and structural vibration.
- Frequency-domain mathematical modeling and analysis are effective for development of the physical understanding needed to make practical high-bandwidth control systems.
- Block diagrams developed in the preliminary design phase must anticipate the numerous special elements of a practical digital system to reduce the heavy and costly reliance on redesign and optimization of design during the flight-testing phase.
- Emulation analysis (which involves an analog half-sample-period-delay approximation of the performance of an analog-to-digital converter) is useful in preliminary design and performance tradeoff studies, but direct digital analysis is necessary to evaluate accurately the many important high-frequency dynamic characteristics of a modern digital system.
- The methods of analysis presented in the report require the availability of flexible, in-



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teractive computational tools.

This work was done by M. B. Tischler of **Ames Research Center**. *To obtain a copy of the report, "Assessment of Digital Flight Control for Advanced Combat Rotorcraft," Circle 14 on the TSP Request Card.*
ARC-12187

Multiple-Baseline Interferometric Synthetic-Aperture Radar

Performances of spaceborne systems and effects of phase errors are discussed.

A report discusses the performances of spaceborne interferometric synthetic-aperture radar (SAR) systems in terms of the utility of SAR echo data in the generation of topographic maps. In the interferometric SAR (INSAR) approach, conventional digital SAR echo data taken along nearly-repeat ground tracks are combined coherently to synthesize interferometric SAR data. The resulting interferograms yield data on the height of the terrain in each picture element.

Airborne INSAR has already been shown to yield maps comparable with conventional topographic contour maps. The purpose of the report is to demonstrate the potential utility of INSAR in a spaceborne setting to obtain global coverage. To illustrate the concept, the report uses a set of SEASAT data on the Cottonball Basin of Death Valley, taken from five orbits that were close enough to each other so that adjacent ones approximated the two-antenna configurations of airborne SAR. The Cottonball Basin was chosen because it is dry and, therefore, was not expected to change significantly during the 3-week interval that contained the nearly repeating orbits. (Any change would increase phase noise.)

The report discusses the processing of the raw SEASAT data, including such problems as the registration of the separate complex-amplitude SAR images. The accuracy of the resulting topographical measurements is assessed.

Particular attention is given to phase-measurement errors, a mathematical model of which is described. The model has important implications for the design of future spaceborne INSAR. It shows among other things that, although the sensitivity in the measurement of altitude increases with the baseline separation, so does the phase error. Indeed, there appears to be an optimal baseline separation that balances these two opposing factors. The model is compared with interferograms synthesized from the data obtained at the various baseline separations (between orbits), and it is found to agree qualitatively with the interferometric data.

This work was done by F. K. Li and R. M. Goldstein of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Studies of Multi-baseline Spaceborne Interferometric Synthetic Aperture Radars," Circle 97 on the TSP Request Card.*
NPO-17416

Detecting Impacts of Particles on Spacecraft

The locations and types of impacts would be determined electronically.

A report describes a proposed network of acoustical sensors — in effect, a miniature seismographic system — to detect impacts of particles on the external panels of a spacecraft. Inexpensive thin-film vibration sensors would be placed on the insides of the panels and would be connected to a relatively-simple data-collection system. The meteoroid shields already planned for the Space Station would serve as the panels on that spacecraft.

As many as 10 panels on the Space Station logistics module, each 1.4 meters square and containing typically 10 sensors, would be used to show the feasibility of the concept. An integrated-circuit chip for each sensor would convert its output into digital format and feed the output through a data buffer to a trigger circuit, which would select signals from neighboring sensors when a sensor produces a signal above preset level. The system would use the signals to locate the position of an impact and to calculate the characteristics of the impact, such as its amplitude in time and frequency, its rise time, and its phase spectrum. The Space Station panels would be recovered every 6 months so that the impact craters could be examined directly.

The report describes tests of the concept in which small spheres impinged on aluminum panels. The tests showed that the sensor data can be used to determine the locations and characteristics of impacts and that the panels provide a suitable medium for detecting the low-probability impacts of interest. However, the success of the method depends on the further development of data processing. In addition, more-sensitive sensors — perhaps embedded acoustic waveguides — will be needed to raise the probability of detecting impacts of 0.1 g/s above the present level of 0.3 per panel per 6-month period.

This work was done by Brian M. Lempriere, Robert L. Carlsen, and James M. Nelson of Boeing Aerospace Co. for **Marshall Space Flight Center**. *To obtain a copy of the report, "Final Report, Task 5, Space Debris Measurement, Mapping and Characterization System, Space Station Integrated Wall Damage and Penetration Damage Control," Circle 141 on the TSP Request Card.*
MFS-28278

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Physical Sciences

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Reducing Heating in High-Speed Cinematography

Simple filters are effective.

Lewis Research Center, Cleveland, Ohio

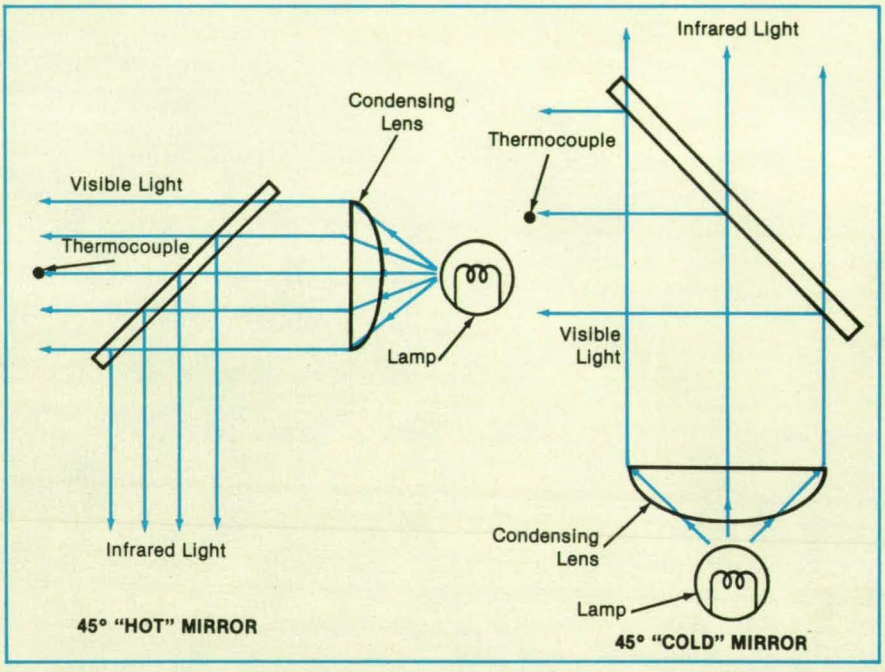
Infrared-absorbing and infrared-reflecting glass filters are simple and effective means for reducing the rise in temperature during high-speed motion-picture photography. High-intensity lights are needed, but the heat generated by the lights can be excessive, sometimes damaging the objects to be photographed and creating an unsafe working environment.

High-speed photography involves rates of about 4,000 frames per second. Most film sequences are finished in less than 10 s, but the greatest temperature rise above the ambient temperature occurs during that interval.

In an experiment, a thermocouple with a digital readout was used to measure the rise in temperature caused by radiation from a 300-W tungsten lamp when a heat-reflecting mirror (a "hot" mirror) or a heat-transmitting mirror (a "cold" mirror) was placed between the lamp and the thermocouple (see figure). With a hot mirror perpendicular to the rays from the lamp, the temperature rose from an ambient 76.4 °F to 129 °F (54 °C) within 10 s after the lamp had been switched on. Without the mirror, the temperature rose to 163 °F (73 °C). The hot mirror, which passes most of the visible spectrum but reflects most infrared light away, thus reduced the rise in temperature by 39 percent.

A hot mirror at an angle of 45° to the optical path was even more effective. It allowed the temperature to rise to only 121 °F (67 °C) — a reduction of 48 percent below the rise in the unfiltered case. A cold mirror, which reflects most visible light and allows most infrared to pass, was tested at an angle of 45°. It allowed the temperature to rise to 106 °F (41 °C) at 10 s — a reduction of 66 percent below the rise in the unfiltered case.

A single hot or cold mirror in combination with a heat-absorbing glass produces an even greater reduction in the rise in temperature. At 10 s, the temperature was 98 °F (37 °C), representing a reduction of 75 percent in the rise in temperature.



These **"Hot-Mirror" and "Cold-Mirror" Configurations**, often employed in projection of images, can also help prevent excessive heating of scenes by powerful lamps used in high-speed photography.

This work was done by Howard A. Slater of **Lewis Research Center**. *Further information may be found in NASA TM-100222 [N88-11100], "Reduction of Temperature Rise in High-Speed Photography."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700. *LEW-14798*

Four-Mode Squeezing for Optical Communications

Quantum noise and vulnerability to nonquantum noise can be reduced.

NASA's Jet Propulsion Laboratory, Pasadena, California

Experiments have demonstrated the potential of four-mode squeezing (a special example of ultrasqueezing) for increasing the immunity to noise in fiber-optical communication systems and interferometric devices. Four-mode squeezing reduces quantum noise more than does ordinary (two-mode) squeezing and provides partial immunity to non-quantum-mechanical phase noise that arises in such media as optical fibers. Ultrasqueezing can be a strong effect, even in devices in which ordi-

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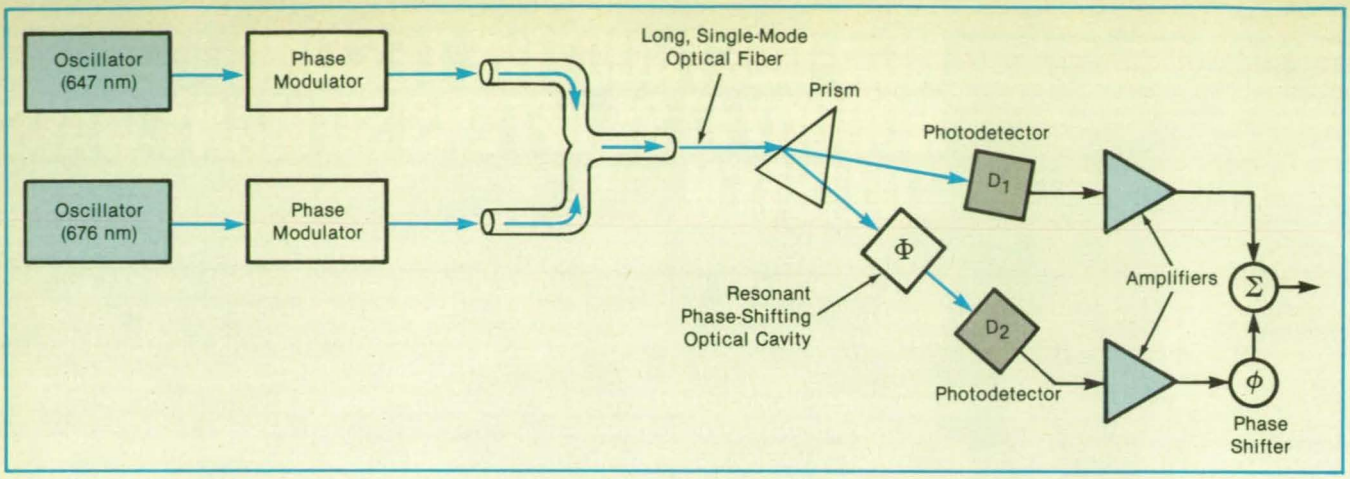

Four-Mode Squeezing is produced in this experimental apparatus by four-wave mixing in the optical fiber.

nary squeezing is a weak effect.

Four-mode squeezing in a fiber or other Kerr medium is the product of a four-wave mixing interaction. The transmitter is a pair of modulated oscillators, which pump a nonlinear medium at two well-separated optical carrier frequencies. (Two-mode squeezing involves pumping at a single optical carrier frequency.) The sidebands of each pump frequency interact with each other and with those of the other pump frequency. The resulting nonclassical four-mode correlations produce light that is squeezed in a quantum mechanical sense. The quantity measured by a dual-frequency homodyne detector has smaller fluctuation than would be measured with light from a perfectly stable (except for quantum fluctuations) laser or with no light at all; i.e., vacuum.

The figure illustrates schematically an apparatus used in fiber experiments of four-mode squeezing. The oscillator signals were at the 647-nm and 676-nm laser wavelengths of singly ionized krypton. Both signals were coupled into a 114-m single-mode optical fiber, a nonlinear Kerr medium. The fiber was maintained at a temperature of 2 K to suppress thermal noise. A resonant phase modulator was used to broaden the spectrum of each oscillator signal to avoid the stimulated Brillouin effect. (The strong phase modulation did not interfere with the squeezing because the relative phases of all significant excitations were preserved.) Typical power levels at the exit of the fiber were 140 to 160 mW at 647 nm and 50 to 60 mW at 676 nm.

After passing through the fiber, the two wavelengths were separated by a prism. One of the wavelengths was incident directly on photodiode D_1 in a heat sink. The other wavelength was reflected from a phase-shifting cavity (optical phase shift Φ), then detected by photodiode D_2. The signals from both photodiodes were amplified, and the amplified signal from D_2 was subjected to a variable electrical phase shift ϕ before the currents from the two amplifiers were combined.

Experimental runs were distinguished by whether the less powerful beam (type I run) or the more powerful beam (type II run) was directed toward the phase-shifting cavity and detector D_2. The combined detector outputs in the both types of runs exhibited four-mode squeezing, with the noise dipping to 20 ±2 percent below the vacuum level. The type II runs gave more dramatic evidence of the effect of four-mode over two-mode cancellations in producing the noise reduction. When $\phi = 0$, the parametric-mixing interaction responsible for two-mode squeezing reduced the net noise level near the optical phase of the four-mode-squeezing minimum, while when $\phi = \pi/2$, these effects opposed each other.

Phase noise due to thermal fluctuations of the index of refraction of the fiber, which is the major obstacle to the observation of four-mode squeezing, was minimized by choosing the optical phase shift Φ, the oscillator powers, and the amplifier gains so that the negative correlation between the two photocurrents predominated over the thermal phase-noise contribution from D_2. Under these conditions, appreciable suppression of quantum noise due to four-mode squeezing could be observed.

This work was done by Bonny L. Schumaker of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 58 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 14]. Refer to NPO-17170.

Spatial Modulation of Light in GaAs

An image is transferred from one beam of light to another.

NASA's Jet Propulsion Laboratory, Pasadena, California

The spatial modulation of light in gallium arsenide (GaAs) has been demonstrated by transferring an image from one of two coherent, crossing beams of light to the other one. The technique relies on cross-polarization beam coupling, which is a special case of beam coupling in a photorefractive crystal.

In the ordinary beam-coupling process, two beams intersect in a crystal of GaAs, which is photorefractive. The resulting interference pattern gives rise to a periodic distribution of trapped electrical-charge carriers, the electric field of which varies the local index of refraction via the electro-optical effect. Thus, a refractive-index grating is formed, and it diffracts the beams of light in such a way that one of the diffracted beams interferes constructively with its incoming beam while the other interferes destructively with its incoming beam. The result is a net transfer of energy from one beam to the other. However, diffracted beams cannot be separated from the passing-through beams.

The image is transferred in a GaAs crystal via cross-polarization beam coupling. The crystal is oriented so that the components of the electric fields of the two beams that lie in the plane of the two electro-optical axes bisect the angle between the two axes. The electric field of each beam can be decomposed mathematically into two equal components, each parallel to one of the two axes. Because the changes in the index of refraction along the two axes are equal in magnitude but opposite in sign, the diffracted beam of one component of a beam interferes constructively with that beam, while that of the other component interferes destructively. This causes the electric field of the resultant diffracted beam to rotate 90° from that of the incoming beam, resulting in a polarization rotation in each beam after the crystal. There is

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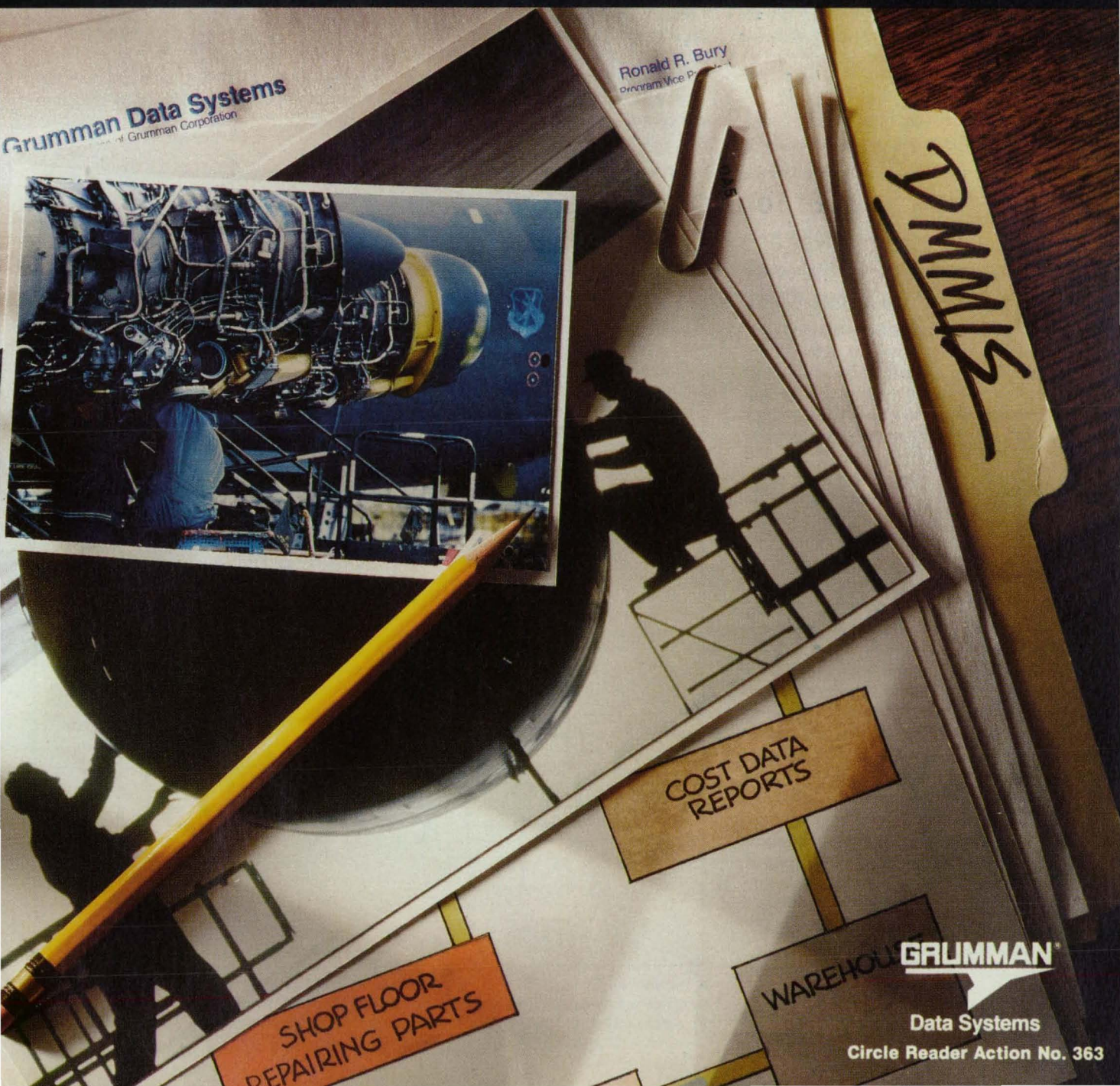

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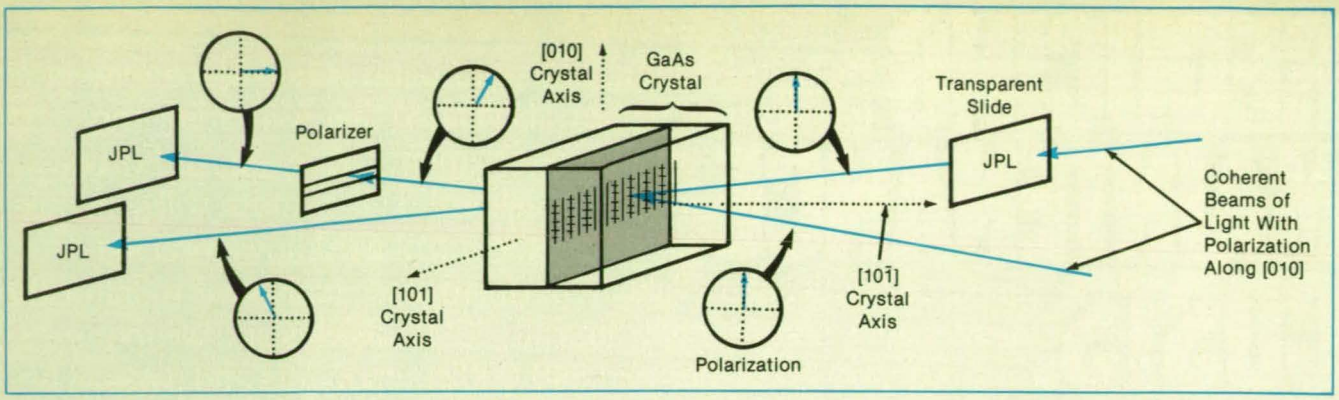

An **Image Is Transferred** from one coherent beam of light to the other by crossbeam coupling, a product of the photorefractive effect in the GaAs crystal.

no net transfer of energy from one beam to the other. The diffracted component of each beam is separated from the beam by a polarizer. Then the transfered image in the diffracted component is observed.

The figure illustrates schematically a cross-polarization beam-coupling apparatus. The crystal is undoped GaAs grown by the Czochralski technique. Two coherent beams polarized along the [010] axis of the crystal are generated by a YAG:Nd laser. One beam passes through a transparent slide that bears the letters "JPL." The polarizer can be adjusted to produce either a positive or a negative of the image on the slide.

This work was done by Li-Jen Cheng, Gregory Gheen, and Afshin Partovi of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 102 on the TSP Request Card.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

Edward Ansell,
Director of Patents and Licensing
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Refer to NPO-17228, volume and number of this NASA Tech Briefs *issue, and the page number.*

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A small, rugged unit gives accurate data in a harsh environment.

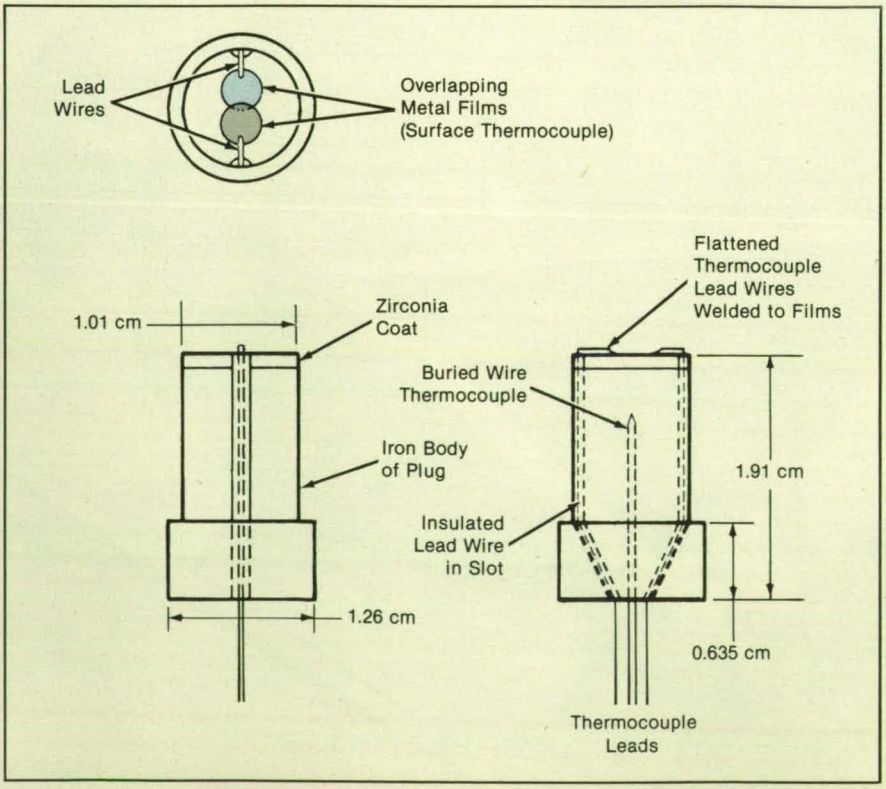
Lewis Research Center, Cleveland, Ohio

A heat-flux sensor includes a buried wire thermocouple and a thin-film surface thermocouple, both made of platinum and platinum with 13 percent rhodium. The sensor is intended for use in a ceramic-insulated, low-heat-rejection diesel engine at temperatures of about 1,000 K.

The body of the sensor is an iron plug. One end of the plug is coated with yttria-stabilized zirconia. Thin films of Pt and 0.87 Pt/0.13 Rh are then sputter-deposited on the zirconia layer through a metal mask so that they form slightly overlapping circles (see figure). The relatively-large nonoverlapping area allows ample space for welding lead wires (and rewelding, if necessary) and for testing the adherence of the films without damaging the thermocouple junction. The circular configuration helps to minimize concentration of stress in the films. The wire thermocouple is embedded in the core of the plug.

Procedures have been established for preparing the surface of the plug, sputtering the films, and welding the lead wires in ways that maximize the adherence of the various layers. First, a bonding coat is applied to the plug. The zirconia is plasma-sprayed on the bonding coat, chemically cleaned in solvents in ultrasonic baths, baked, plasma-etched, and covered with an electrically insulating alumina bonding coat 2 μm thick. The platinum and platinum/rhodium films are sputtered to depths of 5 and 3 μm, respectively. The insulated lead wires are exposed at their tips and attached to the films by a parallel-gap welder.

A prototype sensor performed reliably in engine tests for 10 hours at mean surface temperatures up to 950 K. When the maximum combustion-cycle temperature rose above 1,150 K, however, the all-platinum



A **Thermocouple Junction** that resists the environment in the cylinder of an advanced high-temperature diesel engine is created by depositing overlapping films of Pt and 0.87 Pt/0.13 Rh on an iron plug. The plug also contains an internal thermocouple.

film developed blisters. The adhesion of this film may be improved by deposition of a layer of platinum oxide 300 μm thick under the platinum film.

This work was done by Walter S. Kim, Richard F. Barrows, Floyd A. Smith, and John Koch of **Lewis Research Center**. *Further information may be found in NASA TM-100798 [N88-18892], "Prototype Thin-Film Thermocouple/Heat-Flux Sensor for a Ceramic-Insulated Diesel Engine."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.

LEW-14830

Achromatical Optical Correlator

The signal-to-noise ratio should exceed that of a monochromatic correlator.

NASA's Jet Propulsion Laboratory, Pasadena, California

An experimental optical image-correlating device is illuminated by multiple-pinhole diffraction of dispersed white light instead of the monochromatic, coherent light usually employed in holographic systems. The use of noncoherent light is expected to increase the signal-to-noise ratio by reducing the component of noise attributable to the unwanted component of interference in

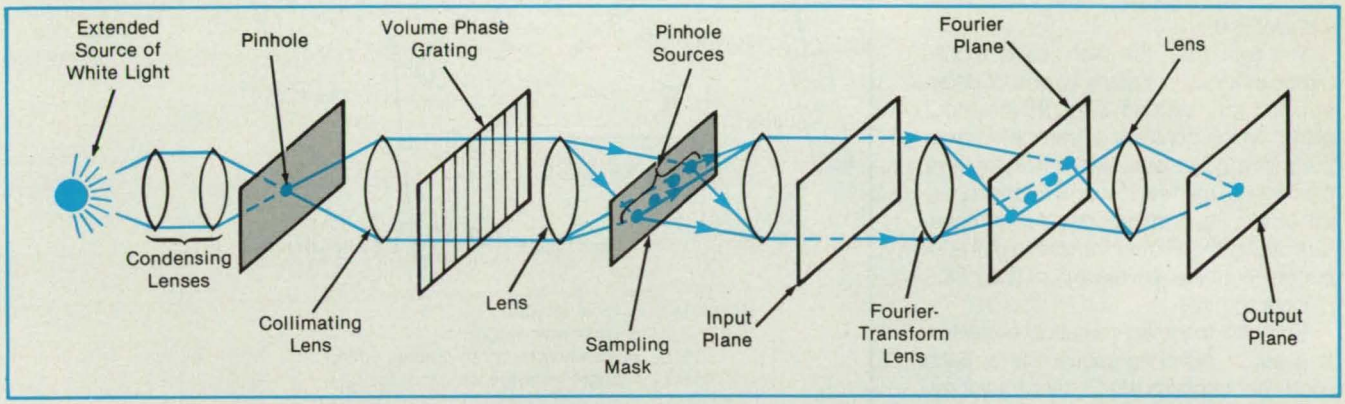


Figure 1. The **Achromatical Optical Correlator** uses multiple-pinhole diffraction of dispersed white light to form superposed multiple correlations of the input and reference images in the output plane.

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coherent light. Furthermore, noncoherent illumination is suitable for applications involving the recognition of color and the determination of scale. When fully developed, achromatical correlators are likely to be useful for the recognition of patterns; for example, in industrial inspection and the search for selected features in aerial photographs.

The achromatical correlator is illustrated schematically in Figure 1. White light is condensed onto a pinhole, then converted by two lenses and a grating into a horizontal-line spectrum. A sampling mask is placed so that a horizontal linear array of pinholes lies in the line spectrum. Thus, each pinhole acts as a point source of light over the narrow range of wavelengths that illuminates it.

The light from the pinholes is recollimated into multiple plane waves of different tilts and passed through the input plane, which contains a transparency of the image to be tested. A lens then focuses the light into multiple discrete Fourier spectra of this input image, each such spectrum being the Fourier transform of the input object at the wavelength of one of the pinhole sources.

Essential to the achromatical correlator is a set of matched spatial filters. Each such filter contains the Fourier transform, at the wavelength of one of the pinhole sources, of a scaled version of the reference image with which the input image is to be compared. Provided that the set of matched spatial filters is aligned correctly in the Fourier-transform plane, the image formed in the output plane is a superposition of the correlations between the input and reference images at the wavelengths of the pinholes.

The matched spatial filters are made by using a laser to make a Fourier hologram at the Fourier-transform plane as shown in Figure 2. For this process, the input image to produce the filter for each pinhole wavelength is the reference image scaled by the ratio of the laser wavelength to the wavelength at the pinhole. A pivotable mirror is used to tilt the reference beam to the angle appropriate to this wavelength.

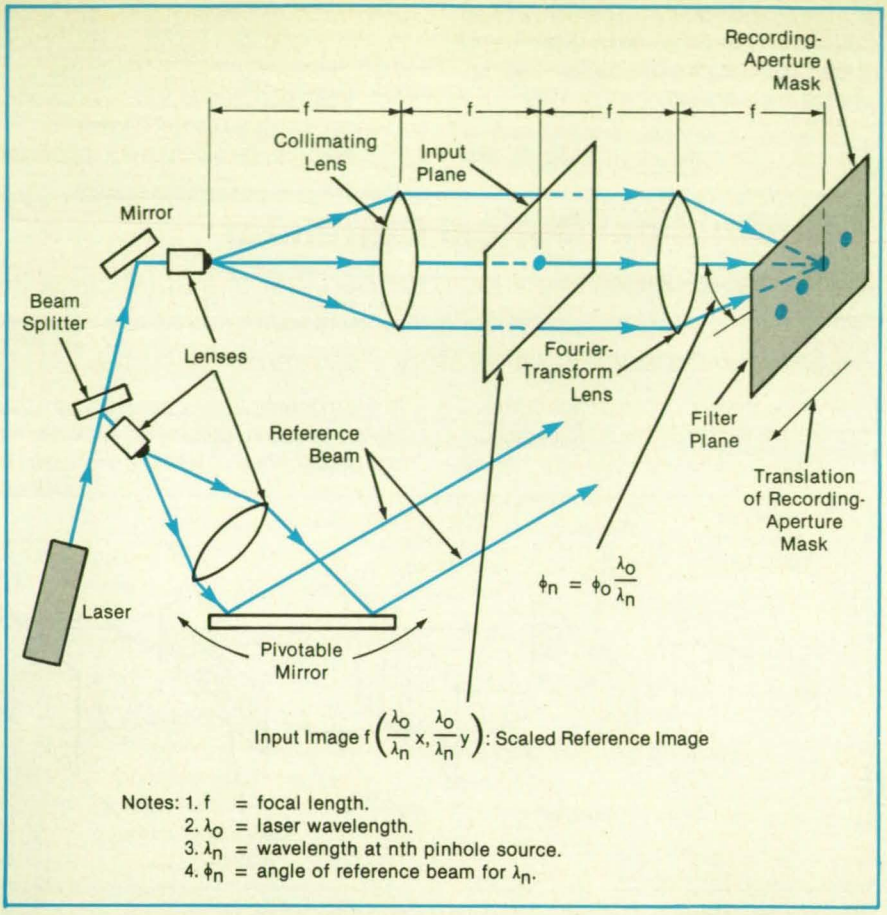


Figure 2. The **Set of Matched Spatial Filters** is made by a multiple-exposure holographic process, each exposure using a suitably-scaled input image and a suitable angle of the reference beam. The recording-aperture mask is translated to the appropriate horizontal position for each exposure.

This work was done by Tien-Hsin Chao and Hua-Kuang Liu of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 33 on the TSP Request Card.*
NPO-17206

Boundary-Value Problem for Magnetic-Cutoff Rigidities

Field equations can yield an overview of motions of many charged particles.

NASA's Jet Propulsion Laboratory, Pasadena, California

An alternative approach has been developed for the calculation of the magnetic cutoff rigidities of electrically-charged particles in a static magnetic field. In contrast with the conventional formulation, in which the trajectories of particles are traced by solution of the equations of motion, the new formulation involves a partial differential field equation that is treated as a boundary-value problem. In this approach, the tracing of trajectories is needed only to supply boundary conditions.

"Rigidity" is used here in the astrophysical sense meaning the ratio of momentum of a particle to its electrical charge. Typically, the rigidities of particles arriving at a given location from a given direction can be grouped into bands of rigidities, within which the particles cannot escape to infinity, and outside of or between which they can escape to infinity. "Cutoff rigidity" denotes the least upper bound or the greatest lower bound of such a band. Thus, the calculation of cutoff rigidities is important in such endeavors as estimating the degree to which magnetic fields could protect spacecraft from solar-flare particles, designing experiments in atomic physics, and extracting energy from nuclear-fusion reactions.

The mathematical development begins with the basic equation of motion of a relativistic charged particle in a magnetic field. The rigidity is substituted for the momentum in this equation to obtain a differential equation in terms of the rigidity, the magnetic field, and displacement along the trajectory. Another differential equation is introduced to express the constancy of rigidity along the trajectory. The foregoing equations are combined and manipulated to yield two alternate forms of the partial differential field equation for the cutoff rigidity:

$$\hat{\mathbf{P}}\cdot\nabla_x F + (\hat{\mathbf{P}}\times\mathbf{B})\cdot(P/F)\nabla_p F = 0$$

and

$$\hat{\mathbf{P}}\cdot[\nabla_x F + \mathbf{B}\times(P/F)\nabla_p F] = 0$$

where P is the rigidity (magnitude of the rigidity vector $P\hat{\mathbf{P}}$), $\hat{\mathbf{P}}$ is the unit vector tangent to the trajectory in the direction of the

rigidity, F is the cutoff rigidity, ∇_x is the gradient operator in position space, ∇_P is the gradient operator in rigidity space, and **B** is the magnetic-flux-density vector.

Once the field equation is supplemented by boundary conditions, and subject to requirements of existence and uniqueness of solutions, a solution should be obtainable. When the magnetic field is axisymmetric (e.g., in a cylindrical solenoid or in a dipole approximation of the magnetic field of the Earth), the equations can be simplified considerably when one considers the generalized Stormer cutoff. It can be shown that the vertical cutoff, which is the generalized Stormer cutoff evaluated in a direction perpendicular to magnetic east, is constant on a magnetic-field line. This means that the cutoff can be evaluated at an arbitrary location by following the magnetic-field line that passes through that location until it intersects a surface on which the cutoff has been specified as a boundary conditon.

Analytic solutions for the cutoffs can be obtained for a large class of problems with axial symmetry. A procedure for finding the magnetic field that provides the best protection against charged particles, subject to a certain kind of constraint, has been derived. Each application of this procedure yields an inequality that can be used as an upper-bound estimate of the protection that can be provided by a given axially-symmetric magnetic field.

This work was done by Larry D. Edmonds of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 25 on the TSP Request Card.*
NPO-17294

Fast Laser Holographic Interferometry for Wind Tunnels

Holograms would be made rapidly in situ.

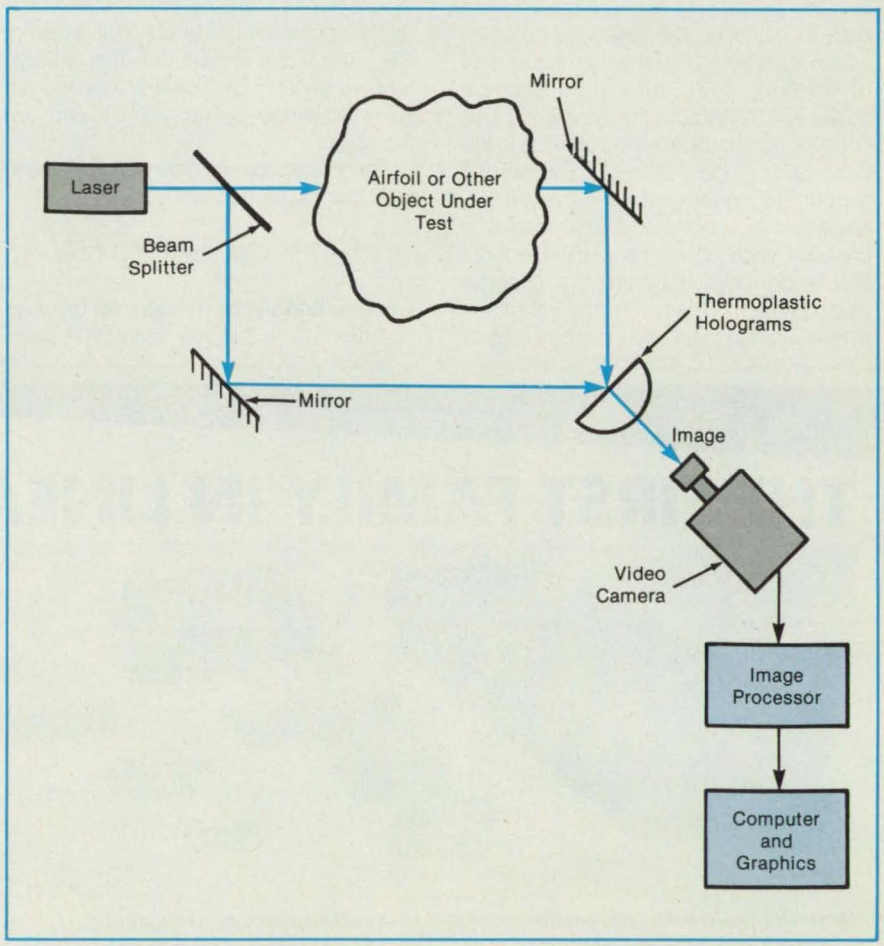
Ames Research Center, Moffett Field, California

A proposed system would make holographic interferograms quickly in wind tunnels. The holograms would reveal two-dimensional flows around airfoils and would provide information on distributions of pressure, the structures of wake and boundary layers, and the density contours of flow fields. Some of the technology needed to build the system is already available. With a concerted effort, a prototype system could be developed in about 2 years.

Because a wind tunnel is a high-vibration, noisy environment, the optics would be mounted on vibration-isolated tables. A laser having a pulse duration very short compared with the vibration period would be used, and the laser would have to be stable — its beam should not wander, and its intensity should remain constant from shot to shot. A neodymium:yttrium-aluminum garnet (Nd:YAG) laser operating at 5,300 Å with 100-ns pulses is a likely candidate.

Recording, processing, and reconstruction of the hologram would be done in place (see figure). The holograms could be formed on photographic film or plates in a commercially-available, self-contained wet-developing unit. Even better, the holograms could be formed in thermoplastic plates in a modified version of a commercially available thermoplastic holocamera. Based on a dry process in which the hologram is developed by heating, the holocamera can produce reconstructed images in less than a minute, instead of the hours required for the usual wet development followed by reconstruction of the image in a laboratory away from the wind tunnel. Moreover, vibration can be compensated simply by adjusting the position of one of the thermoplastic plates in the holocamera.

The system would process and analyze images quickly. A semiautomatic microcomputer-based desktop image-processing unit now undergoing development will be moved easily to the wind tunnel, and its speed and memory will probably be adequate for flows about airfoils. A fully automatic minicomputer-based image processor also undergoing development will incorporate expert-system computer programs to detect fringes, determine the orders of fringes, enhance pictures when necessary, and eliminate noise. An expert-system rules base is now being developed; when complete, it will draw on domain-specific knowledge, relate to past experience, use information from each step of the analysis to select the next step, and make intelligent guesses.



Holograms Would Be Formed Quickly in thermoplastic plates in a wind tunnel. The plates would be rigid and left in place so that neither vibrations nor the photographic-development process would degrade the accuracy of the holograms.

This work was done by George Lee of **Ames Research Center**. *For further information, Circle 156 on the TSP Request Card.*
ARC-11840

Books and Reports

These reports, studies, handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Calculating Response of a Tunable-Diode-Laser Spectrometer

The response function is calculated from measurements by an iterative deconvolution procedure.

A report describes measurements made with a tunable-diode-laser spectrometer and the processing of the measurement data to calculate the response function, which characterizes the component of broadening in the measured spectral peaks due to the spectrometer itself. This broadening results from instabilities in the diode-laser output frequency. By use of a procedure developed to enhance the resolution of spectra and described in a previous publication, the response function is deconvolved from the spectral measurements. The procedure is fast and simple enough to be used to make routine corrections for broadening in diode-laser spectrometers.

In the experiments, two tunable-diode stripe-geometry lasers in a cold head on a vibration-isolation mount were used to cover the spectral regions around wavelengths of 5.8 and 7.5 μm. Rotational/vibrational absorption spectra of CH_4 and HNO_3 were measured in two ways: averaging of multiple scans by the sweep integration technique and by a lock-in amplifier coupled to an *x-y* chart recorder for conventional phase-sensitive detection. Pressures were kept in the range of 10 to 50 mtorr (1.3 to 6.7 Pa) to minimize pressure broadening and were adjusted to yield absorptances of 10 to 40 percent at the centers of the rotational/vibrational peaks. A relative-frequency scale was provided by recording the pattern of interference fringes from a solid 7.62-cm Ge etalon. The relative positions of the spectral peaks of CH_4, which are known to within a wave number of 10^{-4} cm^{-1}, were used to confirm the free spectral range (0.016 cm^{-1}) of the etalon.

The measured (broadened) absorption spectrum $A_m(\nu)$ is given by

$$A_m(\nu) = \int_{-\infty}^{\infty} A_t(\nu')R(\nu - \nu')d\nu'$$

where ν and ν' are frequencies or wave numbers, A_t is the true absorption spectrum of the gas, and $R(\nu - \nu')$ is the desired time-independent response function of the spectrometer. Because a reference gas (CH_4 or HNO_3) of known spectral characteristics is used, one can calculate $A_t(\nu')$ from the known absorption lines and the Doppler-broadening function for the wavelength of the line and the temperature and molecular weight of the gas.

The algorithm for the deconvolution of the response function from the measurements involves sampling at 15 to 25 points over the half width at half maximum of an absorption peak. Typically, averaging the data from 512 sweeps proved sufficient to yield a signal-to-noise ratio of ~400. The signal-to-noise ratio was limited to ~500 by the 9-bit resolution of the signal averager. Smoothing-filter subalgorithms were applied to the data before and during deconvolution to suppress high-frequency noise.

The response functions calculated for various laser modes had half widths at half maximums ranging from 25 to 35 MHz and had shapes ranging from Gaussian to roughly trapezoidal. A Gaussian shape would be expected where the broadening is due to random phenomena like acoustical vibrations or noise in the diode current. In the absence of such broadening mechanisms, the output frequency spectrum of the tunable-diode laser would be expected to be Lorentzian, with a width 1 to 2 orders

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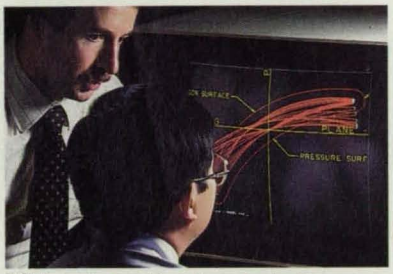

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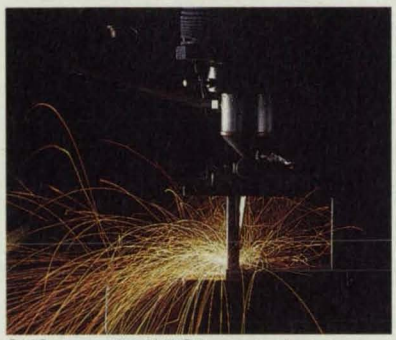

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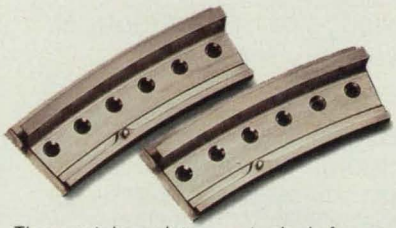

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of magnitude below the widths observed. In this case, the broadening was attributed to noise in the diode current, caused in part by electromagnetic interference from nearby laboratory equipment and by acoustical shocks associated with the piston movement in the closed-cycle cooler.

This work was done by Randy D. May of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Response Function of a Tunable Diode Laser Spectrometer From an Iterative Deconvolution Procedure," Circle 37 on the TSP Request Card.*
NPO-17375

Research in Thermoelectric Materials

Knowledge of microstructures is necessary for further improvements.

A report reviews current research in thermoelectric materials with a view toward the development of materials of greater energy-conversion efficiency. These substances are generally fine polycrystalline conglomerates of high-temperature semiconductors, formed by such standard ceramic-making techniques as the hot pressing of the fine powders of elemental constituents or prereacted powders. The properties depend on the constituents and the fabrication process, which affect the microstructure. The emphasis in the report is on the effort to understand and manipulate the microstructure to increase the thermoelectric figure of merit, Z.

The thermoelectric properties of three broad categories of materials are discussed. The first category includes the alloys of group IV elements like silicon and germanium, which have large energy gaps, high chemical stability, and high melting temperatures that make them suitable candidates for high-temperature thermoelectric generation of power.

Si/Ge alloys are the materials of choice for operation at temperatures up to 1,300 K. The suitable heat treatment of $Si_{0.8}Ge_{0.2}$ doped with GaP has resulted in a Z as high as $1 \times 10^{-3}\ K^{-1}$. Analysis of the microstructure has shown that these alloys are quite inhomogeneous — a property that may be essential to improved performance.

The second category is the rare-earth chalcogenides. These compounds have the general chemical formula $R_{3-x}X_4$ ($0 < x < \frac{1}{3}$) and the crystalline structure of ThP_4 and are important thermoelectric materials because of their high melting temperatures, capabilities for self-doping, and low thermal conductivities. In $La_{3-x}Te_4$, a Z as high as $1 \times 10^{-3}\ K^{-1}$ has been achieved. The optimum Z appears to occur at $x \approx 0.2$, but analysis of the microstructure shows that the exact value of x cannot be defined, partly because of the presence of La_2O_2Te. Consequently, a reproducible, high-Z material cannot be made until contamination by oxygen can be controlled or eliminated.

The third category includes the narrow-band semiconductors, especially the boron carbides, in which electrical conduction occurs by the hopping of quasi-free charge carriers in the form of small polarons. The boron carbides are preferred for operation at temperatures up to 2,000 K. A p-type Z as high as $5 \times 10^{-4}\ K^{-1}$ has been achieved at a temperature of ~1,200 K, with the promise of a higher Z at 2,000 K. The degree of microstructural and compositional disorder appears to influence the thermoelectric properties strongly. Knowledge of the disorder through analysis of the microstructure and correlation of the foregoing with transport properties is essential to further progress with the boron carbides.

This work was done by Charles Wood of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Materials Problems in High Temperature Thermoelectric Energy Conversion," Circle 103 on the TSP Request Card.*
NPO-17403

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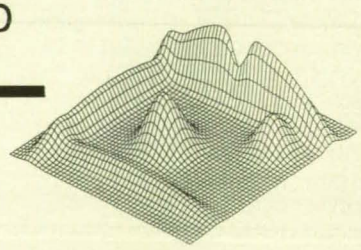

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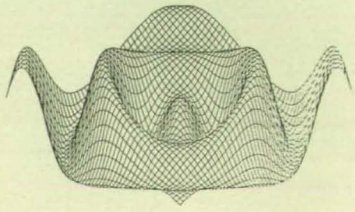

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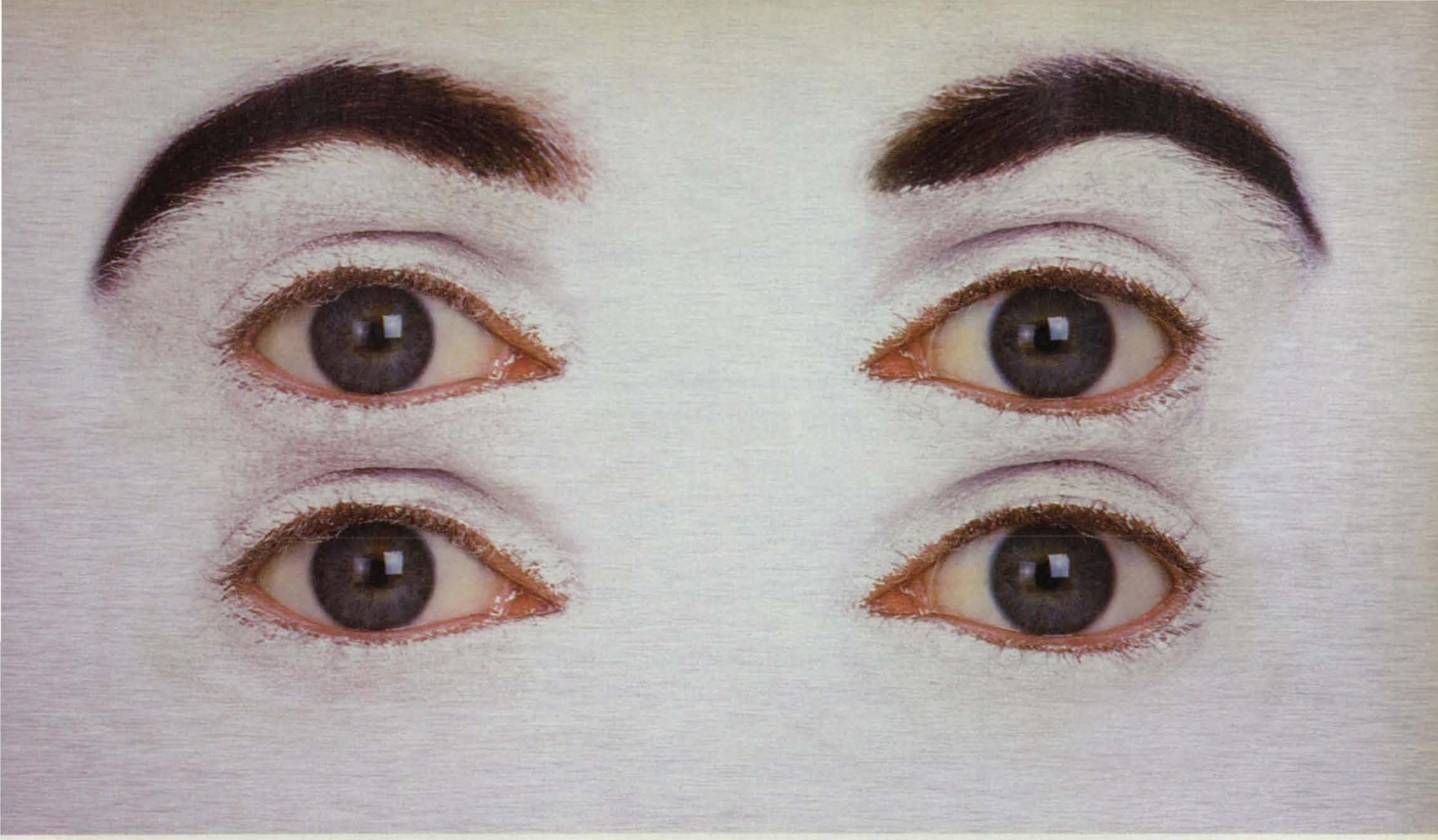

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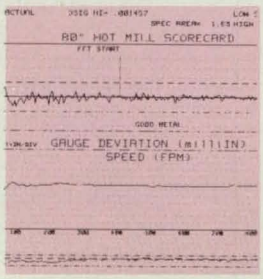

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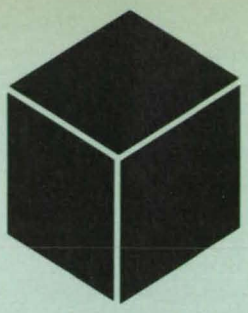

Materials

Books and Reports

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58 Rapid Annealing of Amorphous Hydrogenated Carbon
60 Measuring Mechanical Properties of Optical Glasses

Books and Reports

These reports, studies, handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

PMR Resin Compositions for High Temperatures

One composition showed no deterioration in mechanical properties after 200 hours at 700 °F (371 °C).

A report describes experiments to identify polymer matrix resins suitable for making graphite-fiber laminates that could be used at 700 °F (371 °C) in such applications as aircraft engines to achieve higher thrust-to-weight ratios than are now possible. Two particular high-molecular-weight formulations of PMR (polymerization of monomer reactants) resins appear to be the most promising.

In the experiments, neat resin moldings were prepared with various monomer reactants and screened for thermo-oxidative stability at a temperature of 700 °F (371 °C) in air under both ambient pressure and 4 atmospheres (0.4053 MPa) of pressure. The resins that exhibited the best overall balance of processability, glass-transition temperature, and thermo-oxidative stability were used to prepare unidirectional-graphite-fiber laminates. The laminates were evaluated for thermo-oxidative stability and mechanical properties.

Each of the resins contained a dimethyl ester and the monomethyl ester of 5-norbornene-2,3-dicarboxylic acid (NE), and some resins contained one or two diamines. The stoichiometric proportions of the reactants used in each resin were n:(n + 1):2, where n = the number of moles of dimethyl ester, n + 1 = the number of moles of diamine, and the number of moles of NE was 2. The formulated molecular weights (FMW's) of the end-capped prepolymers prior to final curing of the resin ranged from 1,270 to 7,500.

The formulation of the most promising resin, designated PMR-II-30, was a dimethyl ester of 4,4′-(hexafluoroisopropylidene)-bis(phthalic acid), p-phenylenediamine, and NE in the mole ratio of 5:6:2. After an exposure to air for 200 hours at a temperature of 700 °F (371 °C) and a pressure of 4 atm (0.4053 MPa), laminates made with this resin showed no decrease in interlaminar shear strength or flexural strength and had a weight loss of only 11 percent.

In general, the experiments showed that the PMR compositions of higher FMW exhibit enhanced thermo-oxidative stability. The formation of high-quality laminates with these compositions requires the use of curing pressures higher than those suitable for the compositions of lower FMW.

This work was done by Raymond D. Vannucci of **Lewis Research Center**. *Further information may be found in NASA TM-88942 [N87-16071/NSP], "PMR Polyimide Compositions for Improved Performance at 371 °C."*

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LEW-14658

Electrochemical Studies of Aluminum Coated With Primer

The ac-impedance method is used to investigate corrosion rates and mechanisms.

A technical paper describes experiments using the ac-impedance method of analyzing the corrosion of metal surfaces and the breakdown of protective coatings. Direct-current methods, in use for at least 15 years, enable the quick determination (30 to 60 minutes) of corrosion currents that translate into corrosion rates of mils per year (1 mil/yr $\approx 8 \times 10^{-13}$ m/s). Alternating-current-impedance scans provide more detailed information, which can indicate changes in corrosion rates, progressive deterioration of coatings, changes in metal surfaces, and reaction mechanisms. Moreover, changes in the conditions of coatings can be detected by the ac method before dc methods show an increase in metal-corrosion current.

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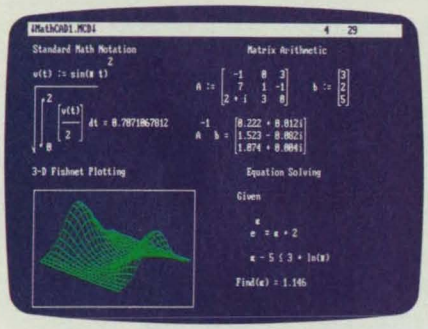

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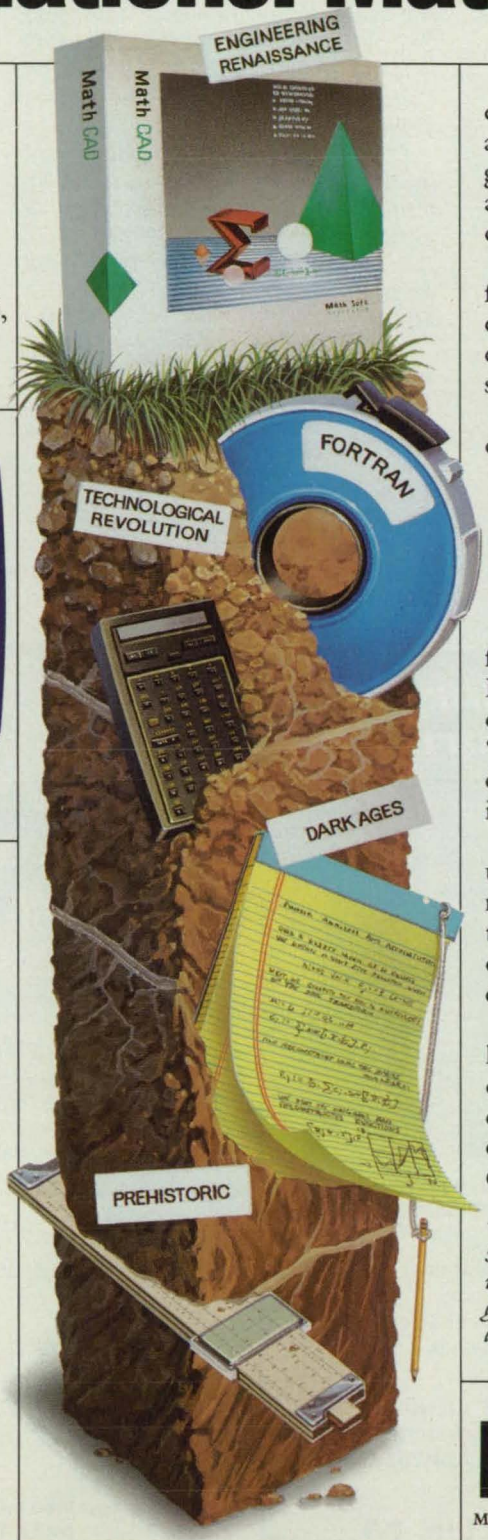

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Circle Reader Action No. 628

For purposes of interpretation of measurements of the ac impedance of a corroding specimen, the equivalent circuit of an uncoated metal specimen immersed in aqueous solution is a resistor (representing the solution) in series with a parallel combination of a capacitor and a resistor (representing the layers of charge at and near the surface of the metal). The equivalent circuit of a coated specimen is more complicated and includes four resistors and four capacitors. The resistances and capacitances change with time as corrosion proceeds.

Measurements of the impedance as a function of frequency provide sufficient data to enable the resistances and capacitances to be determined by performing a least-squares fit. A knowledge of the dependence of these values on time can lead to a more detailed understanding of the corrosion process.

The specimens for the experiments were 2219-T87 aluminum disks coated with TT-P-1757 aerosol zinc chromate primer. The disks were immersed in 3.5-percent NaCl solutions buffered at pH 5.5 and pH 8.2 and monitored for 40 days by both the ac-impedance method and the dc polarization-resistance method.

The ac-impedance data indicate that a charge-transfer mechanism predominates in the kinetics at both pH values. The changes in one of the resistive components have been tentatively attributed to the buildup of corrosion products in the paint film and the subsequent dissolution of those products. The variations in the capacitive components are tentatively attributed to changes in the thickness of the layer of Al_2O_3 on the surface of the aluminum. The resistive curves from the measurements of the ac impedance and the dc polarization resistance are consistent with each other.

This work was done by Merlin D. Danford of **Marshall Space Flight Center** *and Ward W. Knockemus of Huntington College. Further information may be found in NASA TP-2715 [N87-21076/NSP], "The Corrosion Mechanisms for Primer Coated 2219-T87 Aluminum."*

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MFS-27184

Rapid Annealing of Amorphous Hydrogenated Carbon

Effects on selected optical properties are discussed.

A report describes experiments to determine the effects of rapid annealing on films of amorphous hydrogenated carbon (*a*–C:H). This study represents some of the first efforts to provide information for applications of *a*–C:H films where rapid thermal processing may be required.

For the experiments, *a*–C:H films were deposited from a methane plasma onto quartz and silicon substrates. Each of these specimens was placed in a rectangular quartz annealing chamber 5 in. (12.7 cm) wide, 8.5 in. (21.6 cm) long, and 1 in. (2.5 cm) high and heated rapidly from the top and the bottom by a bank of 13 1.5-kW tungsten/halogen lamps.

The specimens were mounted on a silicon wafer coated with gold and tungsten to speed heating through enhanced absorption of light from the lamps. Some specimens were mounted with the film side up and some with the film side down. The temperature was measured by a thermocouple attached to the silicon wafer, and the lamps were operated under control of a microprocessor to obtain the desired variation of temperature with time. Annealing temperatures of 400 or 600 °C were maintained for various intervals from 20 s to 0.5 h.

Annealed and unannealed specimens on quartz substrates were examined with an ultraviolet-and-visible absorption spectrometer. The optical band gaps of these films were inferred from the variations of their absorbencies as functions of the

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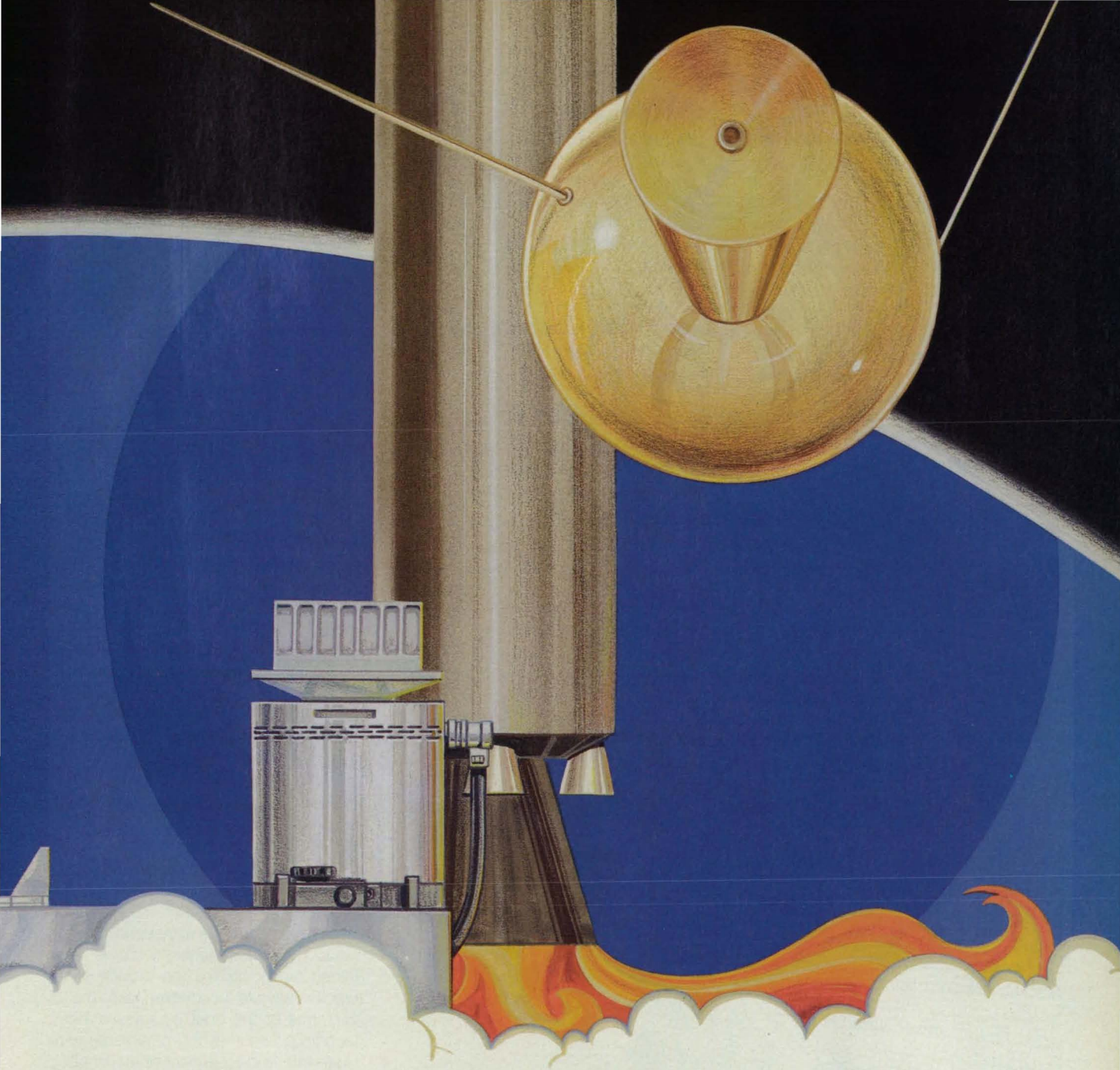

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Circle Reader Action No. 319

photon energy. Annealed and unannealed specimens on silicon substrates were examined with a rotating-analyzer ellipsometer, and the resulting measurements were used to infer the extinction and absorption coefficients, index of refraction, density-of-states parameter, thicknesses, and optical band gaps of these films.

The major finding is that annealing causes an abrupt increase in the absorption and a concomitant decrease in the optical band gap. Most of the change occurs during the first 20 s, though it continues during longer annealing times. The extent of the change increases with the annealing temperature. The researchers hypothesize that the abrupt initial change is caused by the loss of hydrogen, while the gradual subsequent change is due to polymerization of the remaining carbon into crystallites or sheets of graphite.

The optical band gaps of unannealed specimens on silicon substrates were lower than those of specimens on quartz substrates. Because silicon is a conductor while quartz is an insulator, the plasma above the substrates during fabrication is believed to be different, leading to differences between the films, including the observed differences in the band gaps.

This work was done by Samuel A. Alterovitz, John J. Pouch, and Joseph D. Warner of **Lewis Research Center**. *Further information may be found in NASA TM-89859 [N87-20821], "Rapid Thermal Annealing of Amorphous Hydrogenated Carbon (a–C:H) Films."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
LEW-14664

Measuring Mechanical Properties of Optical Glasses

Several tests will yield data relevant to reliabilities and lifetimes under stress.

A report discusses mechanical tests that measure the parameters of strength and fracture mechanics of optical glasses. The data from these tests will be used to predict the reliabilities and lifetimes of glass optical components of several proposed spaceborne instruments.

The inherent brittleness of glass leads to a large variability in measured strength and to a dependence of strength upon time (static fatigue). The rate of loading also affects the strength. Glass that supports loads during long intervals is weaker than glass that is loaded suddenly. Expressing this in terms of fracture mechanics, the purpose of a rapid-loading test is to cause the glass to fail before significant growth of cracks occurs. However, the strength decreases with a decrease in the rate of loading, pursuant to substantial extension of cracks. These properties complicate the structural design of glass components.

Thus, to obtain the required tables of mechanical properties of each glass of interest, both initial-strength and delayed-fracture techniques are used. The modulus of rupture is measured by the well-known four-point bending method. The initial bending strength is measured by the lesser-known double-ring method, in which a disk of glass is supported on one face near its edge by a larger ring and pressed on its other face by a smaller concentric ring. This method maximizes the stress near the center, making it more likely that the specimen will fracture there, and thereby suppresses edge effects.

Fracture-mechanics studies generally involve the measurement of the velocities of propagation of cracks as functions of selected loads and parameters of the environment (e.g., temperature and humidity). Such studies are often directed toward the determination of stress-intensity factors. The crack-tip stresses that cause a crack to grow are directly proportional to the stress-intensity factor, and the critical stress-intensity factor at which fracture occurs is usually expected to be a parameter of the material in question.

In a typical delayed-fracture study, a specimen that contains an initial crack of known length is stressed in a double-cantilever or simple three-point-bending apparatus. The stress-intensity factor is determined by monitoring the growth of the crack relative to a controlled load. The advantages of the double-cantilever-beam technique are that the strain-energy-release rate is independent of the length of the crack and that corrections for shear or rotation of the beam are unnecessary.

For a more complete characterization of properties related to strength, it is also desirable to obtain data on the distribution of sizes of flaws. Flaws on the surface of a specimen can be examined by electron microscopy of a replica of the surface. Thus far, a suitable method to investigate flaws within the specimen has not been selected.

This work was done by Dennis S. Tucker and Ronald L. Nichols of the University of Alabama for **Marshall Space Flight Center**. *To obtain a copy of the report, "The Development of Test Methodology for Testing Glassy Materials," Circle 94 on the TSP Request Card.*
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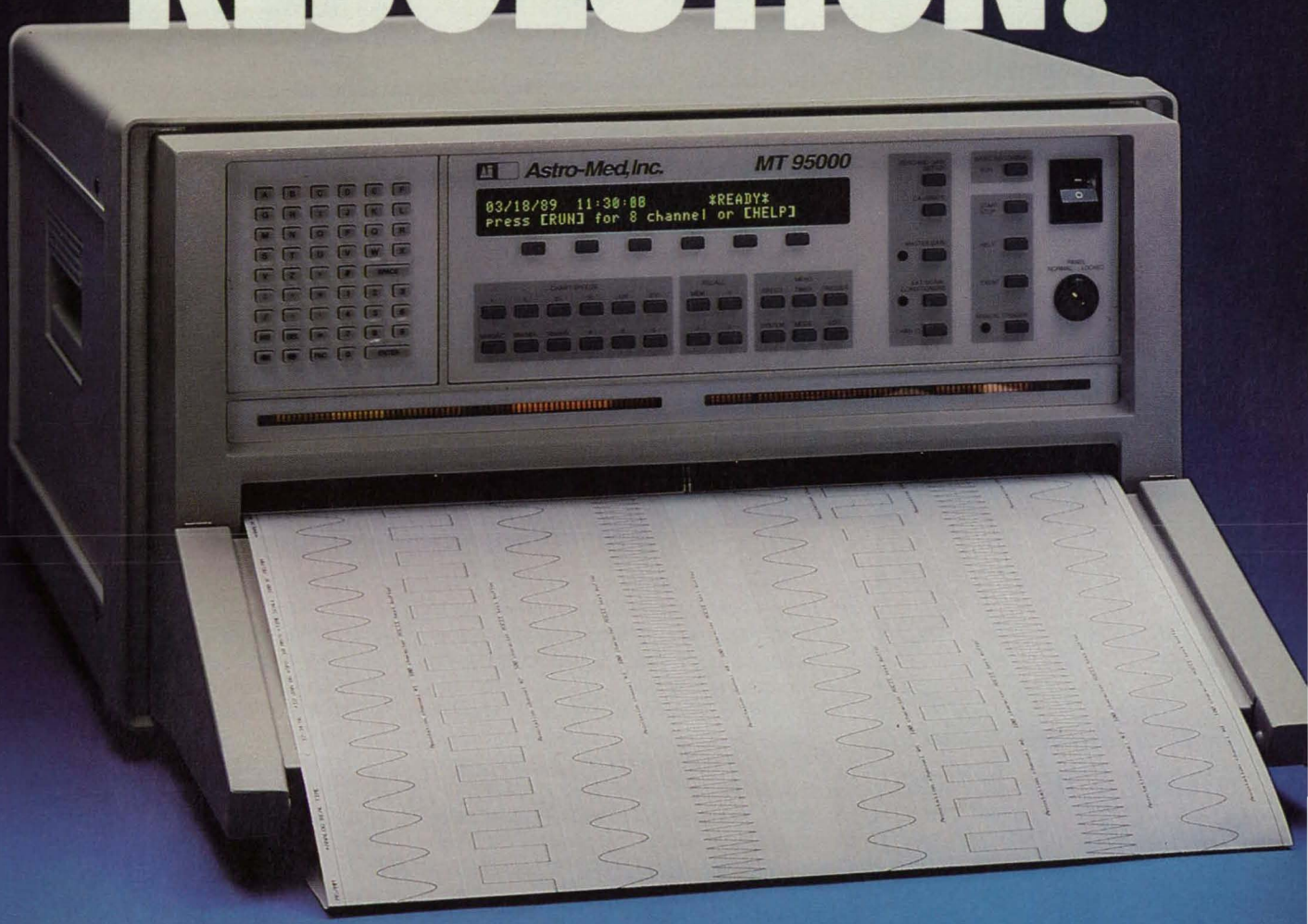

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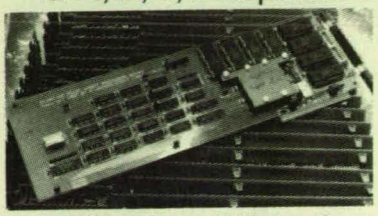

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Computer Programs

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Mechanics

Predicting the Propagation of Cracks

Safe operating lives of components of structures can be estimated.

Flaws and cracks in a structure can grow under fatigue-inducing loads and, upon reaching a critical size, cause the structure to fail. The growth of these flaws and cracks may occur at load levels well below the ultimate load-bearing capabilities of the structure. The Advanced Crack Propagation Predictive Analysis Program, FLAGRO4, was developed as an aid in predicting the growth of preexisting flaws and cracks in structural components. FLAGRO4 provides the fracture-mechanics analyst with a computerized method of evaluation of the "safe crack-growth life" capabilities of structural components. FLAGRO4 could also be used to evaluate the tolerance-to-damage aspects of a given structural design.

The propagation of an existing crack is governed by the stress field in the vicinity of the tip of the crack. The stress-intensity factor is defined in terms of the relationship between the magnitude of the stress field and the size of the crack. The propagation of the crack becomes catastrophic when the local stress-intensity factor reaches the fracture toughness of the material.

FLAGRO4 predicts the growth of a crack by use of a two-dimensional model that independently predicts the growth of the flaw in two directions based on the calculation of stress-intensity factors. The analyst can specify that the rate of growth be controlled by Collipriest's equation, Forman's equation, Paries' equation, or tabulated data supplied by the user.

FLAGRO4 can model partly-through, through, and corner cracks located on panels, on edges of panels, at open holes, at holes or lugs loaded with pins, and on tub or bar surfaces. The mathematical modeling of the growth of a crack can be continued until propagation becomes catastrophic. FLAGRO4 can accommodate transitions from partly-through to through cracks, gradients of stress across the width and thickness, residual stresses at cold-worked holes, variations in the properties of materials due to changes in the environment, and Willenberg retardation.

The input to FLAGRO4 consists of the initial definition of a crack (which can be defined automatically), type of rate solution, type and geometry of flaw, properties of the material (if they are not in the built-in material table), data on the load spectrum, load-stress functions, and design-limit stress levels. The output from FLAGRO4 includes an echo of the input with any error or warning messages and a history of propagation of the crack.

FLAGRO4 is written in FORTRAN IV for batch execution and is available in CDC, IBM, and DEC machine versions. The CDC version has been implemented on a CDC 6000-series machine with a central-memory requirement of approximately 150K (octal) of 60-bit words. The IBM version has been implemented on an IBM 360-series machine with a central-memory requirement of approximately 260K (octal) of 8-bit bytes. The DEC version has been implemented on a DEC VAX 11/780 computer operating under VMS. The FLAGRO4 program was developed in 1979.

This program was written by Hu Tianlai of Rockwell International Corp. for **Goddard Space Flight Center**. *For further information, Circle 145 on the TSP Request Card.*
GSC-13084

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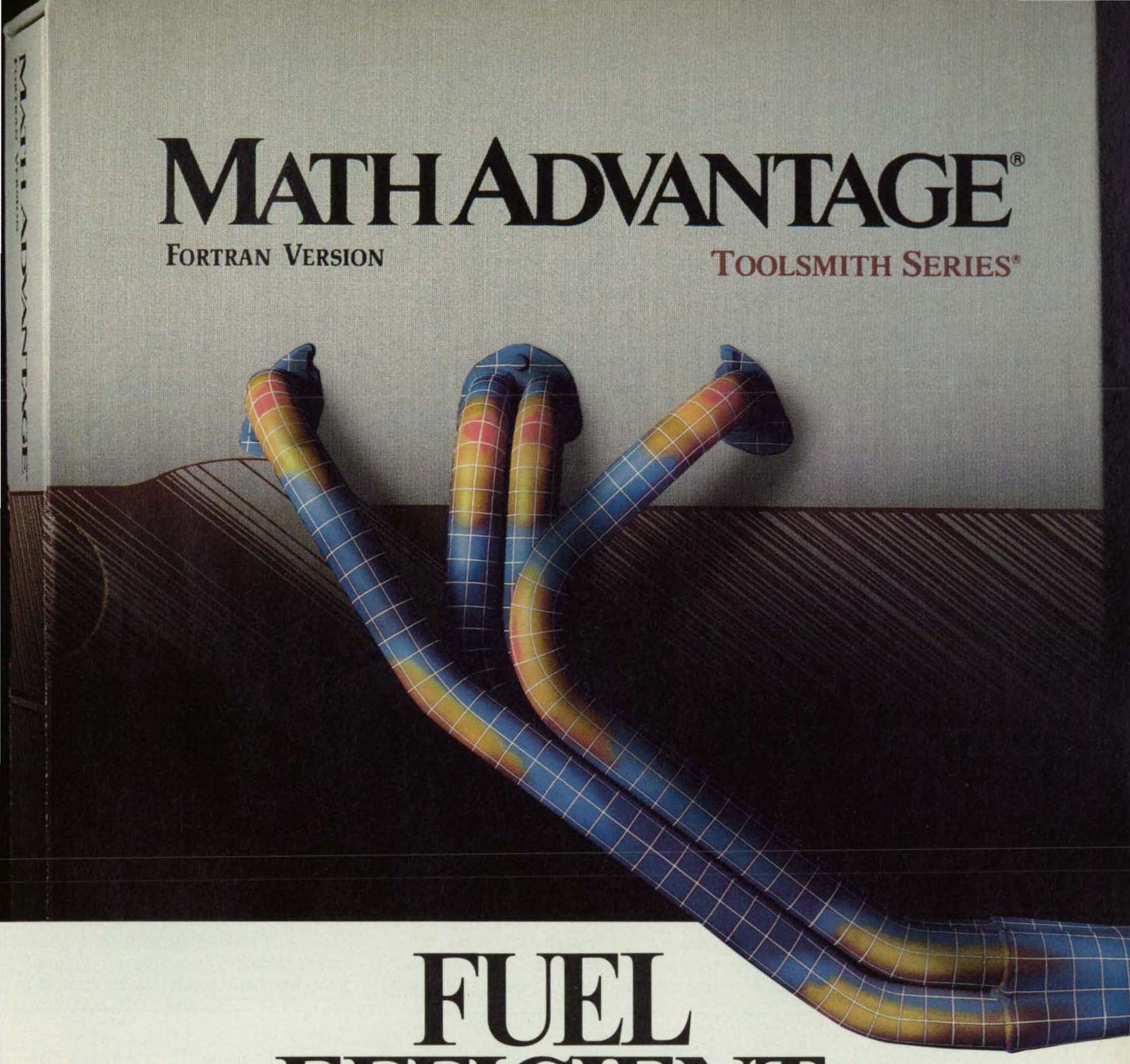

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Mechanics

Hardware Techniques, and Processes

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Carbon/Carbon Panels Cooled by Heat Pipes

Heat pipes are embedded to suppress hotspots.

Langley Research Center, Hampton, Virginia

A durable and reusable high-temperature carbon/carbon heat-pipe structure operates at temperatures above 3,000 °F (1,649 °C) in a vacuum or inert environment and up to 2,800 °F (1,537 °C) in an oxidizing environment. The maximum heat-flux capability of a carbon/carbon structure is currently limited by the temperature capability (about 2,800 °F) of its oxidation protection system. The new concept combines high-temperature heat-pipe and carbon/carbon technologies to extend both the thermal structural capabilities of refractory-metal heat pipes and the maximum heat-flux capability of carbon/carbon structures.

This new design uses refractory-metal heat pipes embedded within a carbon/carbon structure (see figure). The walls of the heat pipes are thin and contain the working fluid (lithium or sodium) of the heat pipe. The carbon/carbon acts as the primary load-carrying part of the structure.

The primary application considered for such a structure is the cooling of the leading edges and/or nose cap of a hypersonic aerospace vehicle. The embedded heat pipes remove high local heat from a leading edge and transport it to cooler aft surfaces, where it can be removed by radiation and/or active cooling. The heat pipes help to eliminate local hotspots and associated thermal gradients and stresses and to reduce peak surface temperatures of the carbon/carbon to levels within the capability of the oxidation-resisting system.

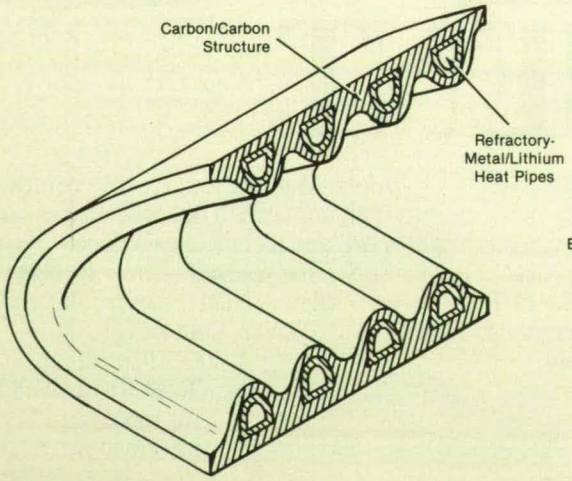
Since the maximum structural-reuse temperature of carbon/carbon [2,800 °F (1,537 °C)] is much higher than that of refractory metals [2,400 °F (1,315 °C)], or superalloys [1,800 °F (982 °C)], the carbon/carbon concept requires less area for radiation and consequently weighs much less. In addition, because carbon/carbon is structurally efficient at high temperatures, this passive design would reduce structural weight and eliminate the need for complex active cooling systems.

Since carbon/carbon is a composite material, its mechanical and thermophysical properties can be tailored to specific requirements by selection of the type of the weave and of the type and condition of the fibers. The optimum choice of properties of the composite and of the size of the heat pipes can result in a minimum-mass design that satisfies peak-temperature and thermal-stress constraints.

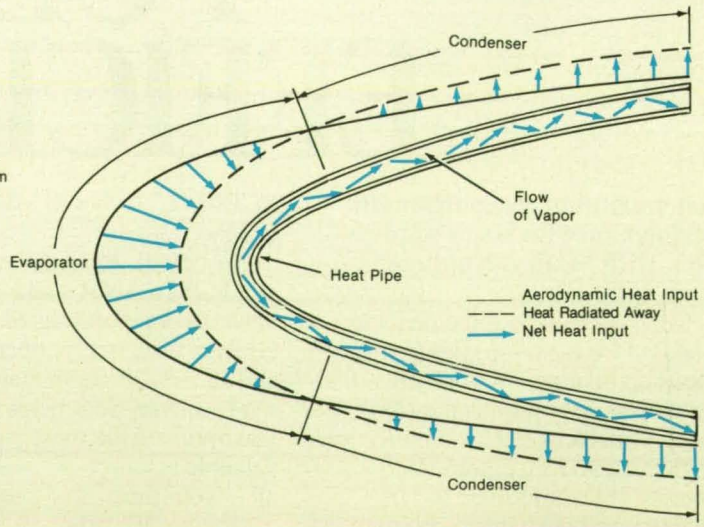
Panels can be made by laminating individual heat pipes between layers of carbon fabric to form two-dimensional reinforced carbon/carbon structural components, or the heat pipes can be incorporated into three-dimensional woven-carbon-fiber preforms by weaving the fibers around the prepositioned heat pipes. The three-dimensional approach provides much higher thermal conductivity and higher strength, which may be required to withstand thermal stresses and prevent delamination.

The most-attractive refractory metal for the fabrication of heat pipes is tungsten because of its compatibility with liquid metal working fluids, its low rate of reaction with carbon, its good mechanical and thermophysical properties at high temperature, and its low coefficient of thermal expansion. Its coefficient of expansion is close to that of carbon/carbon, thereby minimizing thermal stresses.

Since the primary application will likely involve exposure to oxidizing environments, which could rapidly consume the carbon and the refractory metal, the structures must contain systems to protect against oxidation. State-of-the-art systems of this type could protect this structure ef-



CARBON/CARBON LEADING EDGE CONTAINING REFRACTORY-METAL HEAT PIPES



OPERATION OF LEADING-EDGE HEAT PIPE

The **Leading Edge of a Wing** of a hypersonic airplane is cooled by metal heat pipes integrated into the carbon/carbon structure of the wing.

fectively, in cyclic applications, at temperatures up to 2,800 °F (1,500 °C). Coatings currently under development will extend the maximum temperature to 3,000 °F.

This work was done by Charles J. Camarda and Philip O. Ransone of **Langley Research Center**. *No further documentation is available.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 14]. Refer to LAR-13761.

Whistle Gauge Measures Flow and Temperature

Features include simplicity, ruggedness, and compactness.

NASA's Jet Propulsion Laboratory, Pasadena, California

A simple, rugged gauge is used to measure the speed of flow and the temperature of steam or other gas flowing through pipes of arbitrary diameter, from 1 to 28 in. or larger. The gauge — essentially a specially designed, instrumented whistle — has no moving parts, is small, is nonobstructing, can operate at high temperature and pressure, and cleans itself. The gauge does not operate at zero flow, but at moderate flows (tens of meters per second) it can generate intense sound for use in the measurements.

The gauge (see figure) consists of a slanted ring groove of depth D and pressure taps in the wall of the pipe that carries the flow to be measured. The resonant wavelength, λ, of the sound generated by the ring groove depends primarily on the size and shape of the groove and is approximately equal to $4D$.

The pressure taps are openings into narrow tubes separated from each other by an integral multiple of $\lambda/2$ along the axis of the pipe. The sound travels along the tubes to a convenient location at room temperature, where it is sensed by microphones and analyzed to determine the difference in phase between the sound waves at the two pressure taps. Using the Doppler relation for the propagation of waves upstream and downstream from the ring groove, the difference in phase, $\Delta\phi$, is given by

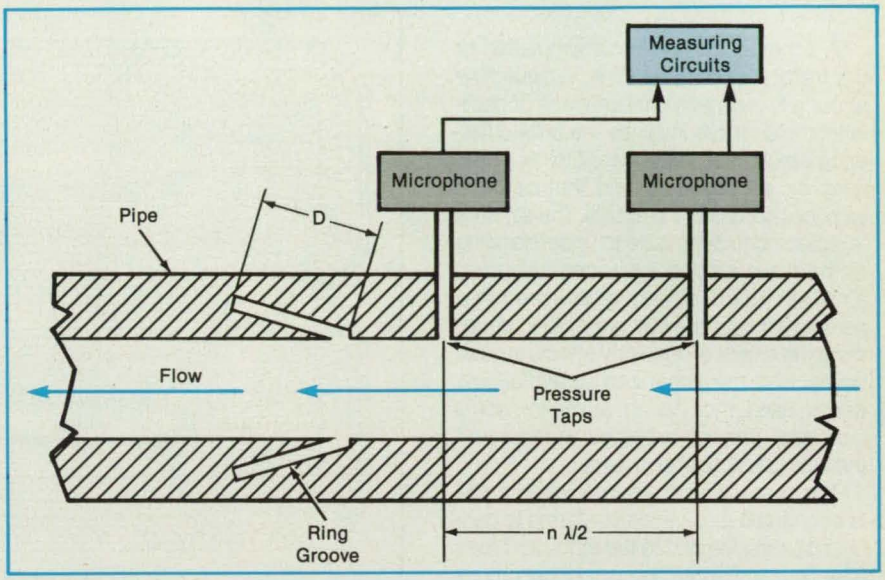
$\Delta\phi = \pi(1 + nu/c)$ when n is odd and

$\Delta\phi = \frac{nu\pi}{c}$ when n is even

where n = the number of half wavelengths between the pressure taps, u = the speed of flow, and c = the speed of sound.

The frequency, f, of the sound is measured, and the speed of sound is estimated by $c = 4fD$. The absolute temperature, T, is then estimated from $T = Mc^2/\gamma R$, where γ = the specific heat of the gas at constant pressure divided by the specific heat at constant volume, R = the gas constant, and M = the mass of one mole of the gas in the pipe.

Experimental versions of the gauge have been tested successfully. For example, one gauge exhibits a resonance at 1,380 Hz at flow speeds of 35 to 110 m/s, and the phase differences were as predicted for pressure taps with one- and two-



The Flow Past the Ring Groove generates a tone that propagates upstream and downstream. The difference in the phase of the tone measured by the two microphones indicates the speed of flow.

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wave-length separations. The introduction of secondary flows of the same gas through a modified ring source at a pressure slightly higher than the local value has extended the range of operation of the sensor down to zero speed.

This work was done by Parthasarathy Shakkottai and Eug Y. Kwack of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 164 on the TSP Request Card.*
NPO-17243

Navier-Stokes Calculations With Deforming Grid

The specification of boundary conditions is simplified.

Lewis Research Center, Cleveland, Ohio

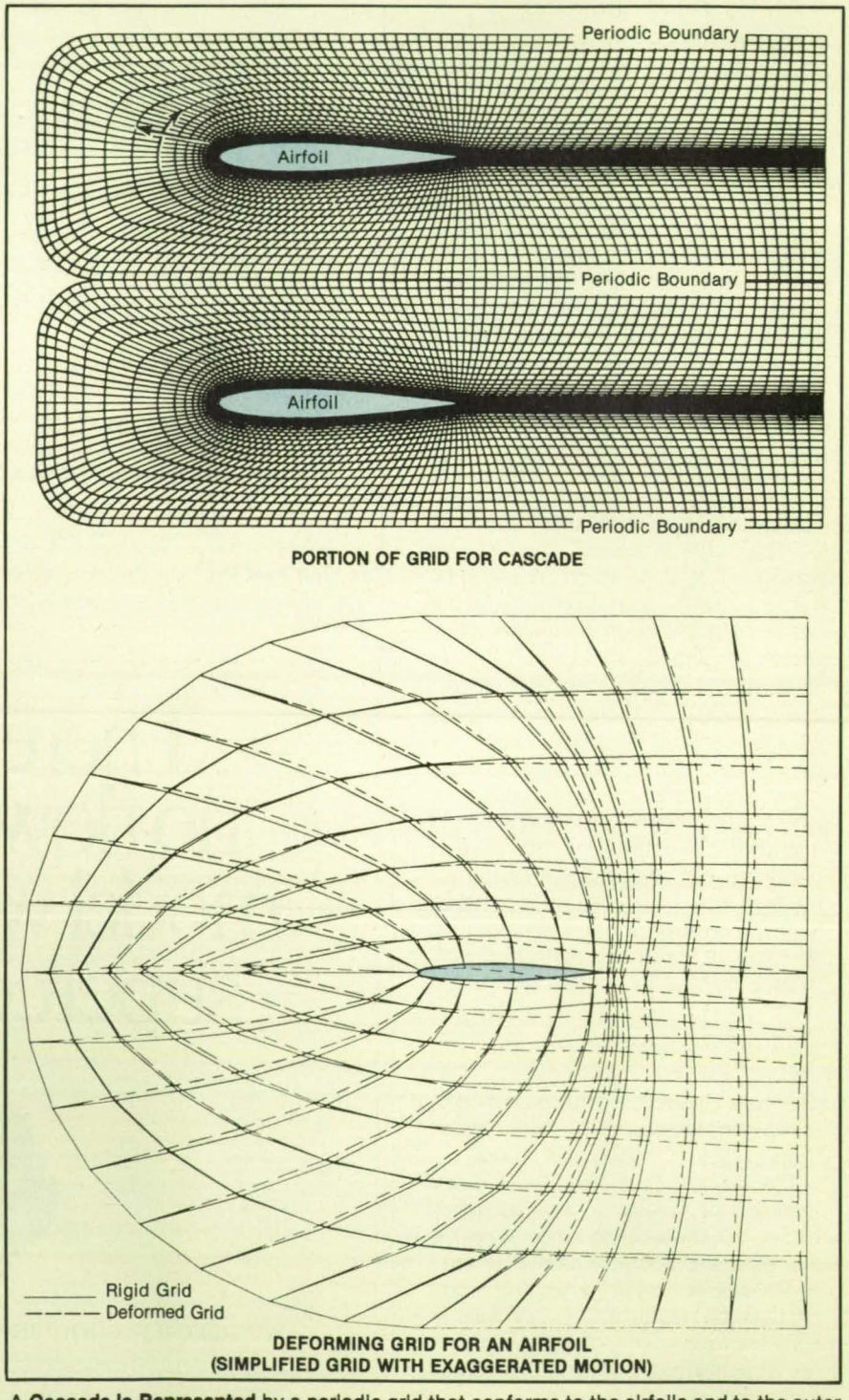
A scheme for numerical simulation of the transonic, compressible, viscous flow about a two-dimensional cascade of oscillating rigid airfoils involves the finite-difference solution of the Navier-Stokes equations on a coordinate grid that deforms with the motions of the airfoils. The scheme is expected to contribute to understanding of the flows around advanced turboprop airfoil sections. It is needed because no experimental data are yet available to determine the extent of unsteady effects in such flows, and the linearized potential-flow codes used thus far to study transonic cascades are not expected to represent the true physical phenomena.

The cascade is represented by a periodic coordinate grid, which conforms to periodic boundaries and to the airfoil surfaces (see figure). Periodic boundary conditions (including blades pitching and/or plunging in unison) are assumed. Thus, the flow about each airfoil can be simulated numerically by applying finite-difference Navier-Stokes-solution techniques previously developed for an isolated airfoil.

The outer boundary is considered fixed. The grid is initially fitted to the outer boundary and a stationary inner boundary (airfoil surface) by a numerical solution of Poisson's equation. The inner boundary is then allowed to move by some prescribed pitching or plunging motion. As the inner boundary moves with the airfoil, the gridlines that connect the inner and outer boundaries deform by amounts that depend on the distance from the airfoil. The total velocity of the flow at any point on the grid equals the local velocity of the deformation plus the velocity of the flow with respect to the grid. The geometric conservation law can be invoked to calculate the effects of the change in the Jacobian of the transformation between the fixed Cartesian grid and the moving computational grid due to the motion of the computational grid.

The inlet boundary conditions are assumed to include the free-stream total pressure and temperature. The direction of the flow across the upstream boundary is approximated as that of a steady flow, using an upstream-running Riemann invariant extrapolated from the interior to give a nonreflecting-boundary condition on the total velocity. The static pressure and density are found by assuming isentropic flow, and the energy density is calculated as the sum of pressure and kinetic-energy-density terms.

The exit boundary conditions are found by extrapolation of the mass density and momentum density from the interior and by specification of a free-stream static pressure to calculate the energy density. (An exit Riemann invariant cannot be specified



A Cascade Is Represented by a periodic grid that conforms to the airfoils and to the outer boundaries. The oscillation of an airfoil is represented by a deformation of the grid.

because it would vary across a viscous wake.) Other boundary conditions include the usual solid-wall boundary conditions on the airfoil surface and averaging of flow conditions across the slit aft of the airfoil.

The results of test computations using the deforming-grid technique were found to agree well with results from an isolated-airfoil calculation using a rigid grid. The inclusion of the geometric conservation law had little effect. Future applications of the deforming-grid technique may include turbomachinery and aeroelastic modeling of nonrigid airfoils.

This work was done by Dennis L. Huff of **Lewis Research Center**. *Further information may be found in NASA TM-89890 [N87-24435], "Numerical Simulations of Unsteady, Viscous Transonic Flow Over Isolated and Cascaded Airfoils Using a Deforming Grid."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700. LEW-14711

Predictions of Fatigue Damage From Strain Histories

Cycle-by-cycle analysis is better than statistical characterization.

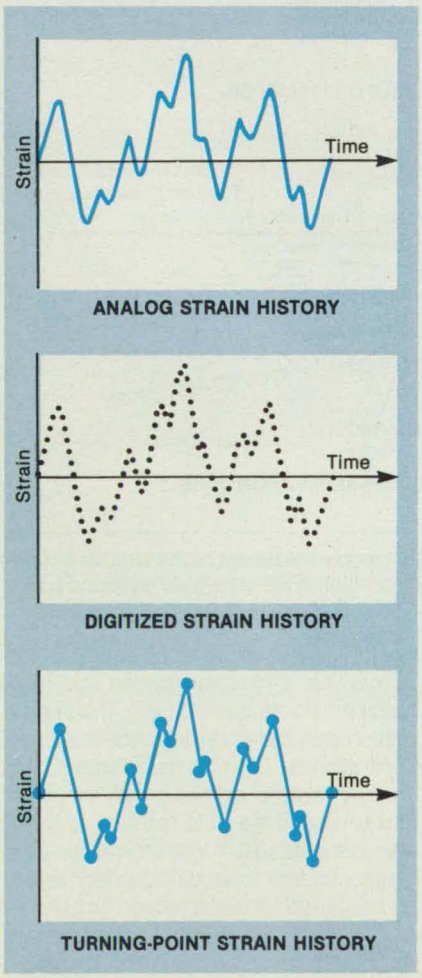
Marshall Space Flight Center, Alabama

A semiempirical mathematical model of fatigue damage in stressed objects uses experimental histories of strains in those objects to predict their fatigue lives. The model accounts for the initiation and propagation of fatigue cracks on a cycle-by-cycle basis. When the model is calibrated against proper test data for each type of object to be characterized, its predictions of fatigue lives are superior to those of such statistical models as one based on root-mean-square strain.

An object to be characterized is instrumented with strain gauges and placed in operation or in a fatigue-testing apparatus. The strain measurements are digitized and fed to a computer operating under the Strain History Life Evaluation Program (SHLEP), which processes the measurements according to the model. The first step in the analysis is to convert the input strain history to a history of turning points (peaks and valleys) of the strain cycles (see figure). The data between the turning points are irrelevant in the model and are removed, thereby significantly reducing the processing time and the number of data to be stored.

Sets of strain cycles are selected for analysis by the ordered-overall-range method, in which the turning-point history is reduced to a history of strain ranges that exceed specified fractions of the range between the maximum and minimum peaks. This method gives an indication of whether or not a large fraction of the total fatigue damage in a particular case is caused by a relatively small number of cycles.

The "rainflow" counting method is used to determine the number of fatigue cycles of various amplitudes after the strain history has been screened for significant ranges. This method involves the counting of cycles that are mathematically equivalent to closed stress-versus-strain hysteresis loops. It is called "rainflow" because a graphical representation of the counting algorithm resembles the path of rain being shed by a plot of the turning-point strain



A **Measured Strain History** is first digitized, then converted to a history of turning-point strains for purposes of the analysis. The data between the turning points are not used.

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history with time running downward along the vertical axis.

For the purpose of the model, the fatigue-crack-initiation life is defined as the fatigue life required to produce a fatigue crack of a preselected depth. In a given case, strain-gauge data may have to be related via a stress-concentration factor to strains and stresses at a fatigue-critical location that cannot be instrumented but which is assumed to undergo strain cycles proportional to those of the instrumented location. The fatigue-crack-initiation algorithm is based on the strain range versus the number of cycles to failure from constant-amplitude fatigue tests. For variable-amplitude fatigue, the damage is evaluated according to a damage fraction, d, given by

$$d = \sum_{j=1}^{m} n_j/N_j$$

where m is the number of strain cycles of all amplitudes in a history, n_j is the number of cycles of the jth amplitude, and N_j is the number of constant-amplitude cycles to failure at the jth amplitude.

The propagation of a crack is considered to begin when the crack-initiation algorithm predicts initiation, defined as the achievement of an arbitrarily-specified damage fraction between 0 and 1. The total fatigue life is the sum of the initiation and propagation lives. Using linear elastic fracture mechanics, the growth of the crack during each cycle is computed for each cycle of a strain history. The sequence is repeated until the crack grows to a critical size at which the part fails. Both the total propagation life and the critical crack size are computed.

This work was done by Robert A. Sire, Philip M. Besuner, and Tim Toomey of Failure Analysis Associates for **Marshall Space Flight Center**. *For further information, Circle 6 on the TSP Request Card.*
MFS-26060

Measuring Laminar-Separation Bubbles on Airfoils

A nonintrusive multielement heat-transfer sensor overcomes limitations of previous methods.

Langley Research Center, Hampton, Virginia

Laminar separation is the major cause of rapid deterioration in aerodynamic characteristics of airfoils at chord Reynolds numbers less than 10^6. At such a chord Reynolds number, a boundary layer is generally stable, and an adverse pressure gradient, as in the rear pressure-rise area, is most likely to result in a laminar separation with or without turbulent reattachment.

A laminar-separation bubble is formed when a turbulent reattachment takes place upstream of the trailing edge of the airfoil, as shown in the upper part of Figure 1. Many flow and geometric parameters affect the laminar-separation bubble, and a good understanding of its characteristics is essential to develop effective practical techniques to control or eliminate laminar separation.

The lower part of Figure 1 is a schematic diagram of a typical laminar-separation bubble. The bubble includes a reverse-flow region close to the solid surface and a zero-mean line that divides the reverse-flow region from the upper entrainment layer wherein the streamlines follow the general outer flow. The height of the bubble is usually a small fraction of a percent of the chord.

The smallness of the height and the complexity of the flow field make conventional measuring instruments like hot-wire anemometers and pitot tubes unsuitable for determination of the characteristics of the bubble because such instruments can perturb the flow significantly. Laser velocimetry is perhaps the most-effective nonintrusive technique, though there are still some problems associated with it. Flush-mounted hot-film sensors have also been ineffective.

A new nonintrusive technique involves a multielement heat-transfer sensor. In tests of the new technique, only small amounts of heat were introduced, and the heated thin films caused little disturbance to the shear layer or to each other. The extent of the laminar boundary layer, the location of laminar separation, the transition in the separated shear layer, and the turbulent reattachment were determined simultaneously.

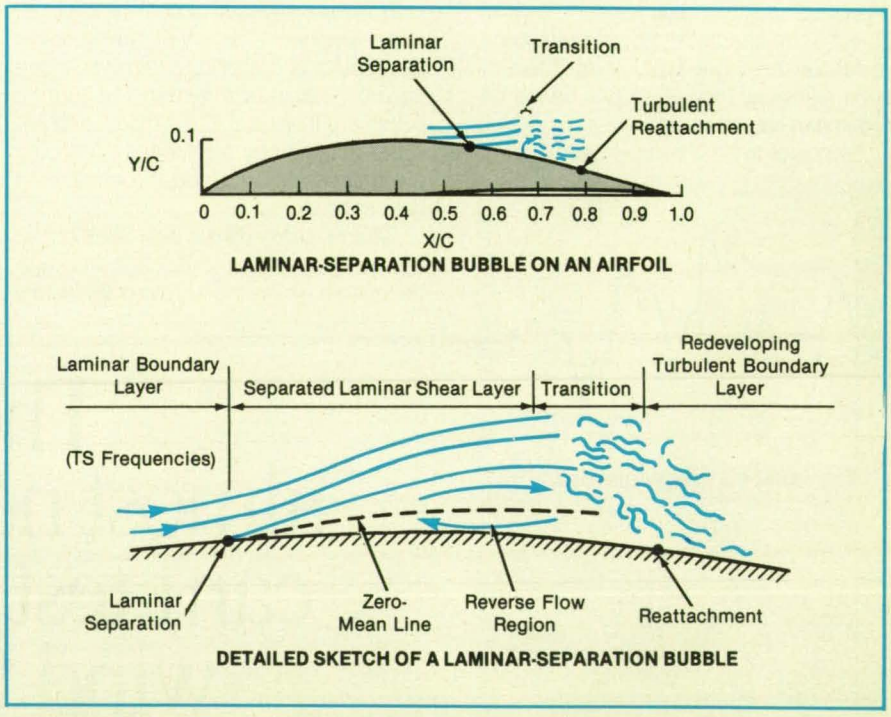

Figure 1. The **New Technique Determines Simultaneously** the extent of the laminar boundary layer and the locations of laminar separation, transition in the separated layer, and turbulent reattachment.

When using the new sensor, there is no need to know a priori the location of the laminar separation; and, in view of the simultaneous measurement, a clear picture of the characteristics of the bubble, including its dynamic behavior, is obtained. In the tests, simultaneous measurements of dynamic shear stress on the surface of the airfoil led to the discovery of a new phenomenon associated with the dynamics of the bubble — a 180° phase shift of low-frequency perturbations was observed across the laminar-separation and reattachment points (see Figure 2). This phenomenon is crucial to the detection of laminar separation by use of a multielement sensor, and its discovery has greatly simplified and advanced the state of the art of multielement surface-film instrumentation as a diagnostic tool to study boundary layers and separated shear layers on an airfoil.

The multielement, surface-film sensor appears to be a promising tool for measurements of the stability of laminar boundary layers, separated shear layers, and transitional separation bubbles. The technique is simple and is capable of providing a comprehensive picture of the state of the

shear flow along the entire surface. There is, thus, a significant saving in tunnel (or flight) test time with a corresponding saving in cost.

The idea can be extended to the diagnostics of more-complex steady and unsteady flow structures at the surface, such as interactions between shocks and boundary layers, wing/fuselage junctures, and other three-dimensional surface-shear layers. The discovery of the phase-reversal phenomenon has made it possible to interpret the characteristics of the surface shear layer in an unambiguous manner and has led to the development of a nonintrusive and cost-effective multielement sensor that can be used in regular wind-tunnel, ground-test, and flight-test applications and may also lead to the discovery of more, hitherto unknown, phenomena in the characteristics of shear flows.

This work was done by John P. Stack of **Langley Research Center** *and Sivaramakrishnan M. Mangalam of Analytical Services and Materials, Inc. For further information, Circle 109 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 14]. Refer to LAR-13952.

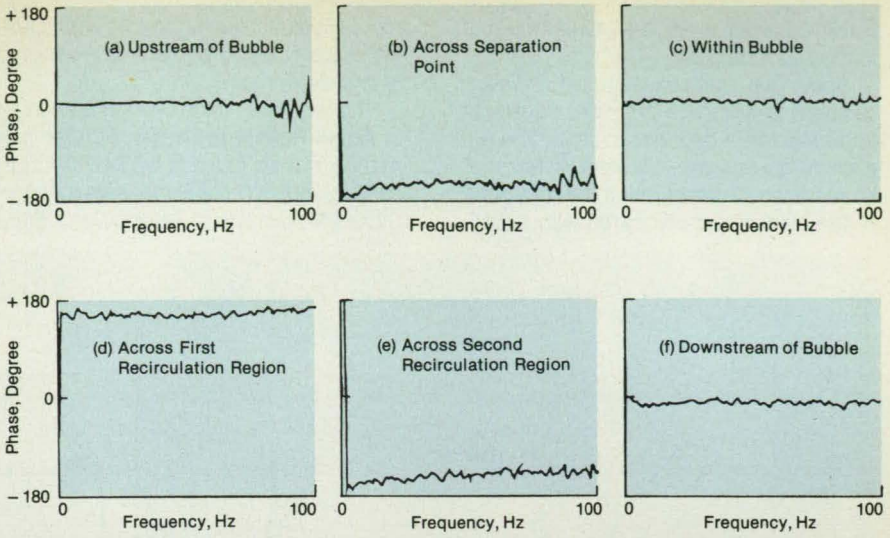

Figure 2. **Differences Between the Phases** of low-frequency sensor outputs show ~180° phase shifts across the points of separation and reattachment.

Navier-Stokes Simulation of Turbine Rotor/Stator Interaction

The patched-grid method is applied to a complicated configuration.

Ames Research Center, Moffett Field, California

The patched-grid method has been used to effect a three-dimensional Navier-Stokes numerical simulation of a flow that interacts with both a rotor and a stator in a turbine. The ability to perform such calculations can contribute to the understanding of complicated turbomachinery flows and to consequent improvements in designs of turbomachinery.

The patched-grid method involves the use of two or more grids or sets of grids to solve the finite-difference versions of the Navier-Stokes or other equations of fluid flow. One grid or a set of grids is attached to the stationary portion of the machinery (in this case, the stator vanes and the housing), while another grid or set of grids is attached to the moving parts (in this case, rotating with the rotor blades and hub). Information is transferred between grids via boundary conditions that satisfy several requirements including numerical stability, spatial and temporal accuracy, easy applicability to generalized coordinates, and flux conservation (in the sense that discontinuities in the flow can move from one grid to another without distortion).

A system of patched and overlaid grids was used to discretize the complicated three-dimensional configuration, including the three-dimensional shapes of the rotor and stator blades, the rotor-tip clearance, and the end walls. An implicit, upwind, third-order-accurate algorithm was used to solve the unsteady, thin-layer Navier-Stokes equations. A modified version of the

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Baldwin-Lomax algebraic model of turbulence was included.

About five blade-passage cycles were required to eliminate the initial transients and establish a periodic solution. The numerical results were expressed in terms of time-averaged pressures at the midspans of the blades and compared with experimental values. As shown in the figure, there was close agreement between theory and experiment.

This work was done by Man Mohan Rai of **Ames Research Center**. *Further information may be found in NASA TM-100081 [N88-29750], "Three-Dimensional Navier-Stokes Simulations of Turbine Rotor-Stator Interaction."*

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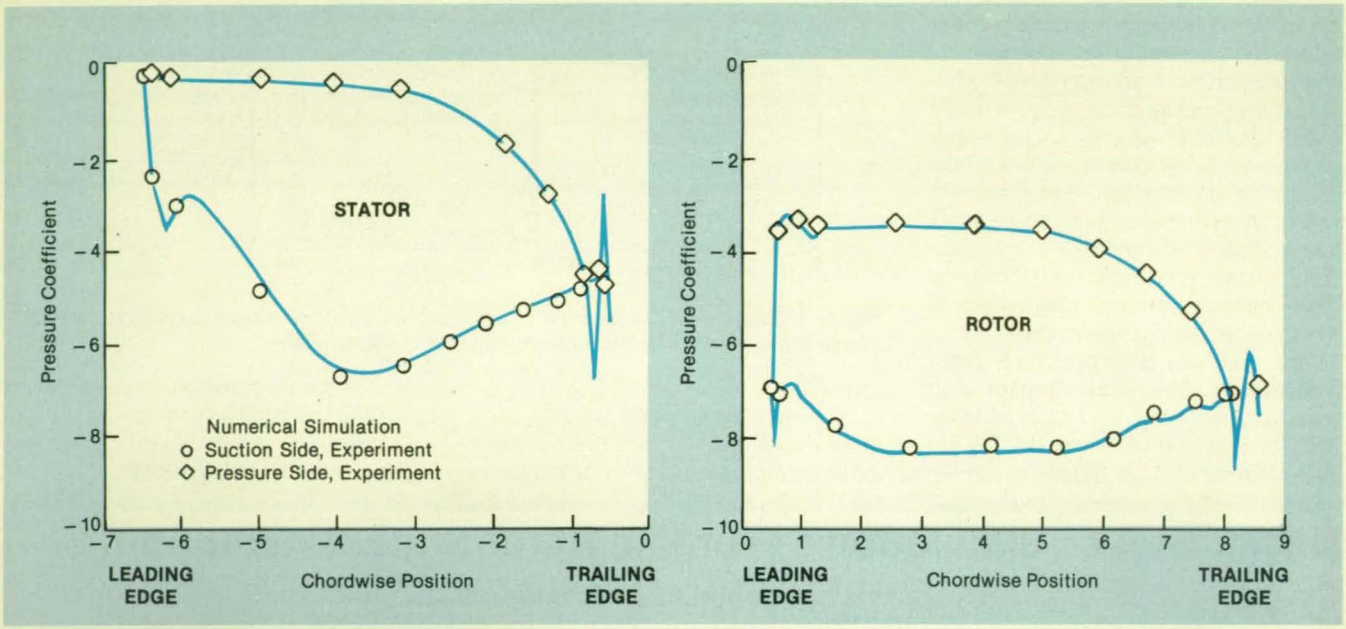


Time-Averaged Pressure Coefficients as a function of position along the chords of the rotor and stator blades at midspan were obtained from a Navier-Stokes simulation and from an experiment. The comparison between the experimental and numerical data is very good.

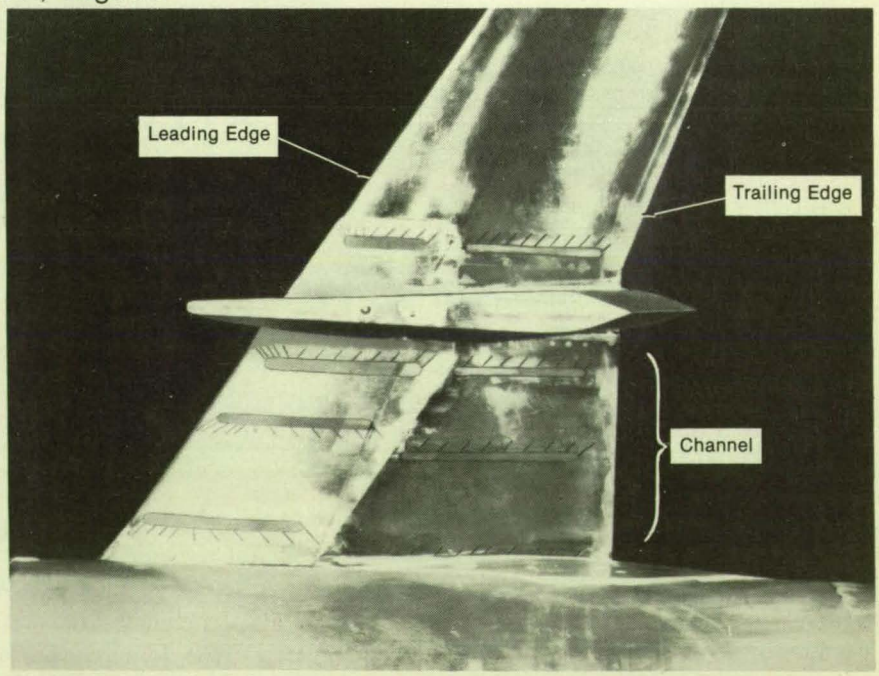
Compression Pylon Reduces Interference Drag

A new design reduces total drag by 4 percent.

Langley Research Center, Hampton, Virginia

The propulsion/airframe integration for a transport airplane normally employs a pylon to attach and position the engine beneath the wing. The side of the fuselage, the underside of the wing between fuselage and pylon, the inboard surface of the pylon, and the nacelle of the jet engine form a channel that influences the aerodynamic flow under the wing. The result is a loss in lift of the wing as well as an increase in drag caused by compressibility effects (wave drag) plus any associated separation of the flow around the pylon.

A new pylon reduces the fuselage/wing/pylon/nacelle-channel compressibility losses without creating additional drag associated with other areas of the pylon. The pylon is designed to compress the flow beneath the wing by reducing the velocity in this channel, thereby reducing the shock-wave losses and, in addition, providing an increase in wing lift. The afterbody of the pylon extends aft of the trailing edge of the wing and is designed to assist the flow in its return to ambient conditions with minimum separation. This additional pylon area may also improve the overall area distribution of the aircraft.



With the **Compression Pylon**, the minimum cross-sectional area of the channel occurs at the trailing edge of the wing. Therefore, the velocity of flow in the channel is always nearly subsonic, reducing the compressibility losses associated with supersonic flow. The flow goes past the trailing edge before returning to ambient conditions, resulting in no additional drag to the aircraft.

Recent wind-tunnel tests were conducted with pylons of various cross-sectional shapes mounted beneath the wing of a high-wing transport configuration. These tests were conducted in the NASA Langley Research Center 16-ft (4.9-m) wind tunnel at the cruise-lift coefficient of 0.43 and mach numbers of 0.70 and 0.80. Because earlier investigations have shown that the drag caused by the wing/pylon/nacelle installation is due mainly to the pylon rather than to the nacelle, these wind-tunnel tests were conducted without nacelles.

The photograph shows the lower surface of the wing with the compression pylon installed. By progressively increasing the thickness of the pylon from the leading edge to the trailing edge of the wing, the minimum channel area is made to occur at the trailing edge. As a result, nearly subsonic velocities are maintained in this area, reducing the compressibility losses associated with pylon installations.

The installed drag for three different pylon configurations was determined. A pylon having a National Advisory Committee for Aeronautics (NACA) 0012 airfoil section was used as a baseline. Cambering an NACA 4412 airfoil section caused a small increase in drag, while contouring the pylon (so that the pylon section followed the natural streamlines under the basic wing alone) resulted in a small decrease. The reduction in compressibility losses achieved by the compression pylon, on the other hand, resulted in a reduction of approximately 4 percent of the total drag of the aircraft model tested.

This work was done by James C. Patterson, Jr., and John R. Carlson of **Langley Research Center**. *For further information, Circle 53 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 14]. Refer to LAR-13777.

Upwind Swirl Coupling in Navier-Stokes Calculations

Convergence in axisymmetric flows is speeded.

Marshall Space Flight Center, Alabama

An improved treatment has been devised for the swirl-coupling source terms in finite-difference Navier-Stokes calculations of axisymmetric flow. The essence of the improvement is to treat the radial- and swirl-velocity source terms in an implicit manner wherever possible, because implicit treatment results in faster convergence and in convergence in some cases in which explicit treatment does not yield convergence at all.

The discretized radial and swirl momentum equations are written as

$$a_i V_i^* + a_{i+1} V_{i+1}^* + a_{i-1} V_{i-1}^* = S_V^n + AW^2$$

and

$$a_i W_i^* + a_{i+1} W_{i+1}^* + a_{i-1} W_{i-1}^* = S_W^n + BVW$$

for all i from 1 to i_{max}, where V represents the radial velocity; W represents the swirl velocity; asterisks denote the predicted values; the subscript indices represent the locations of the nodes; the a's are the discretization coefficients; S_V^n and S_W^n are the radial- and swirl-equation source terms, respectively, at the old iteration level; and AW^2 and BVW are the swirl-coupling terms.

Equations (1) and (2) constitute an implicit system for the predicted velocities V^* and W^*. Because segregated solutions of these equations do not account for the interdependence of the sources, convergence can be impeded where $d(AW^2)/dW$ and $d(BVW)/dV$ are large.

To increase convergence, the radial and swirl source terms are treated in an implicit or explicit manner, depending on the sign of the linearization coefficient. The source term for equation (2) is written as

$$2BVW = BV(1-e)W^* + BV(1+e)W^n$$

where $e = \text{sign}(BV)$. A similar expression is written for equation (1). Thus, when $BV < 0$, the source term is treated implicitly, and the numerical solution converges better than it would if the source term were treated explicitly.

This work was done by Morgan Williams of Rockwell International Corp. for **Marshall Space Flight Center**. *No further documentation is available.*
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Microencapsulated Phase-Change Materials for Storage of Heat

Investigations concentrate on the feasibility of practical, safe, lightweight systems.

A report describes research on engineering issues related to the storage and transport of heat in slurries containing phase-change materials in microscopic capsules. The specific goal of this project is to develop lightweight, compact, heat-management systems that could be used safely in the inhabited areas of spacecraft. Further development of the obvious potential of this technology can be expected to lead to commercialization and use in aircraft, electronic equipment, machinery, industrial processes, and other systems in which the requirements for the management of heat compete with severe restrictions on weight or volume.

The basic principle of operation is simple: to reduce the size and weight of a heat-transport/heat-storage system by taking advantage of the high density of the latent heat of fusion of a material that melts and freezes near the temperature of interest. Techniques that exploit this principle have been investigated since 1932. Work on the microencapsulation/slurry concept began in the early 1970's but was abandoned because of concerns over costs and the premature breakup of the capsules.

For the purposes of this investigation, the choice of materials for the slurry is dictated not only by heat-transfer characteristics but also by the requirements that the materials not be toxic, pose no fire hazard, undergo little or no change of volume in the phase change, and be chemically stable. Also of interest are the rheological properties of the slurry and the specific gravities of the components (with the consequent tendency of the capsules to separate from the liquid in the presence of gravitation and acceleration). The durability of the capsules (partly a function of size and shape and partly a function of the materials) and the costs of materials still give rise to concern as they did during the earlier investigations. A typical candidate slurry that may fulfill most of the requirements could be made of a paraffin wax in polymer capsules suspended in water. A soap or other dispersant could be added to prevent the settling or flotation of the capsules.

The investigation also addressed a number of other topics, including the following:

- Characteristics of the processes and materials used in microencapsulation;
- The storage of heat in modules containing packed beds of phase-change particles through which phase-change slurries are circulated;
- Procedures to test the slurries;
- The development of pumping systems;
- Laboratory data-gathering and experimental fluid systems; and
- The design of experiments to be flown aboard the Space Shuttle.

The achievements include the demonstration of a slurry with a thermal capacitance 10 times that of water and a heat-transfer coefficient twice that of water. An efficient phase-change heat-storage unit was designed, and it was shown that the pump work required to maintain a given overall thermal condition can be reduced as much as 90 percent below that of a comparable system based on water alone. In addition, the enhanced transport and storage of heat in a phase-change slurry take place under conditions that are nearly isothermal in comparison with those of older systems.

This work was done by David P. Colvin of Triangle Research and Development Corp. for **Marshall Space Flight Center**. *To obtain a copy of the report, "Investigation and Development of a Phase Change Thermal Energy Storage System Using Microencapsulated Phase Change Materials," Circle 10 on the TSP Request Card.*
MFS-27198

Survey of Cooling Techniques

Methods of maintaining electronics at the best operating temperatures are reviewed.

A paper surveys cooling techniques for electronic components and sensors that must be kept at temperatures ranging from thousandths of a kelvin to room temperature. The paper discusses the characteristics of the various coolers in terms of ground and space applications, cooling capacity, reliability, and temperature range. It discusses briefly the cooling of conventional electronic circuitry operating a few degrees above the environmental temperature by natural or forced convection of air or liquid. At greater length, it discusses the passive and active refrigeration of "cold" electronic circuitry operating below the environmental temperature.

The simplest and most reliable cooler is a passive radiator. Radiators are seldom used at temperatures below 100 K when the heat load is more than 100 mW because the radiative area required becomes too large.

Other passive coolers depend on such stored cryogens as helium or nitrogen in solid or liquid form. As in melting in an old-fashioned ice box, vaporization or sublimation of the cryogen removes heat. The useful life of a stored-cryogen cooler depends on how quickly the cryogen becomes exhausted, if it cannot be replenished. The paper includes a table of operating temperatures and boiloff rates of common cryogens.

The Joule-Thomson refrigerators are half passive and half active. They cool by expansion of high-pressure gases through nozzles. They can be made very small. However, they depend on constant supplies of gas at high pressures.

Active coolers (closed-cycle refrigerators) are machines that require work to transfer heat from devices to hotter reservoirs. In household refrigerators, the work is done by electric motors. Commercial thermoelectric coolers in cascade can attain temperatures of about 170 K. Cryocoolers, which are fairly well developed, can cool to about 4 K.

Cooling below 10 K is best performed by a closed-cycle Joule-Thomson refrigerator or a magnetic refrigerator, which involves changing the magnetic field in a salt. Below 1 K, either $^3He/^4He$ dilution refrigeration or adiabatic demagnetization can be used.

This work was done by Chung K. Chan of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Survey of Cooling Techniques for Electronic and Sensor Devices," Circle 158 on the TSP Request Card. NPO-17457*

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Circle Reader Action No. 305

Predicting Flutter of a Propfan

Stability decreases as the number of blades increases.

A report discusses a theoretical model and an associated computer program for the prediction of subsonic bending-torsion cascade flutter in propfans. The predictions of the model are compared with the results of experiments. Additional parametric studies illustrate the effects upon the flutter speed of steady aeroelastic deformations, the angle at which the blade is set, the speed of rotation, structural damping, and the number of vibrational modes.

The nonlinear equations of aeroelastic motion are written for a finite-element model of a blade. They are valid for calculating the speeds of stalled and unstalled flutter, forced response, aeroelastic performance, steady-state deflections, and the frequencies and shapes of vibrational modes. Because it is computationally inefficient to integrate them directly in the time domain, the nonlinear equations are treated by a standard perturbation approach, yielding a nonlinear set of equations for the steady-state configuration and a linear set for the perturbations about the steady state. The steady-state deflections and effective total stiffnesses obtained from the solution of the nonlinear equation are used to find the normal vibrational modes. The general vibratory motion is calculated as a superposition of normal modes.

The calculations are performed by parts of the ASTROP computer code: ASTROP 2, based on two-dimensional, subsonic, unsteady aerodynamics; and ASTROP 3, based on three-dimensional, subsonic, steady and unsteady aerodynamics. In ASTROP 2, the blade is divided into discrete aerodynamic strips, within each of which its properties are constant. Each swept strip undergoes plunging and pitching motions. In ASTROP 3, the blade is discretized with nine (radial) times eight chordwise panels for calculating aerodynamic loads.

In general, the flutter speeds and interblade phase angles predicted by the computer code agree well with experimental values. However, the flutter frequencies predicted by a three-dimensional, unsteady aerodynamical theory are slightly higher than measured ones, and those predicted by two-dimensional theory are less accurate than are those predicted by three-dimensional theory. Other findings include the following:

- Steady-state aerodynamics exert significant influence on the steady-state configurations, vibrational modes, and flutter in some cases.
- Both theory and experiment show that stability decreases with an increase in the number of blades, apparently due to effects of cascades.
- Both theory and experiment show that an increase in the angle at which the blade is set is destabilizing.
- For the rotor considered, the flutter mode is dominated by the first two normal vibrational modes of the blades, and there is strong coupling between these modes.
- Both theory and experiment show that under certain conditions, two interblade-phase-angle modes with slightly different frequencies may be present during flutter. The flutter interblade phase angle is a function of the angle at which the blades are set and of the number of blades.

This work was done by K. R. V. Kaza and O. Mehmed of **Lewis Research Center**, *G. V. Narayanan of Sverdrup Technology, Inc., and D. V. Murthy of the University of Toledo. Further information may be found in NASA TM-88944 [N87-18115/NSP], "Analytical Flutter Investigation of a Composite Propfan Model."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
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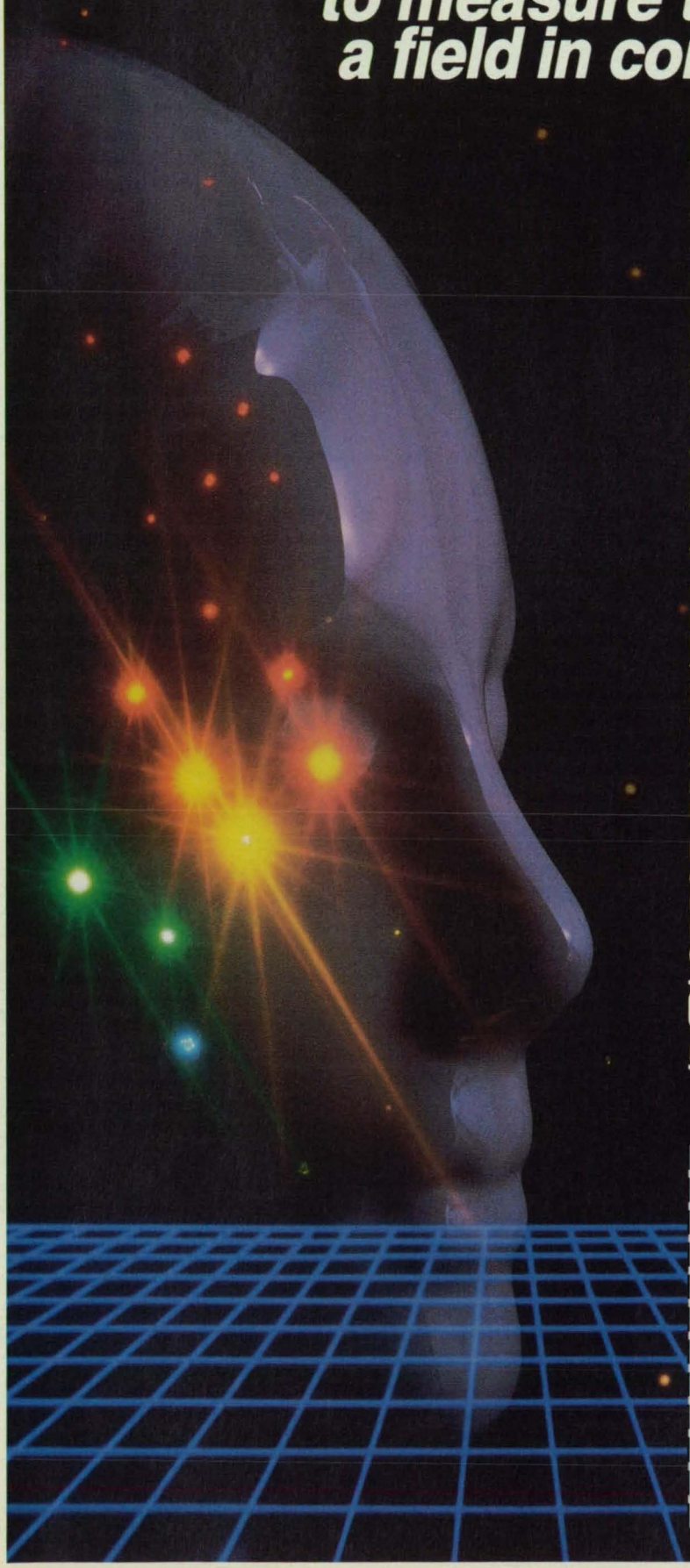

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Circle Reader Action No. 677

Fabrication Technology

Hardware Techniques, and Processes

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83 Circularity-Measuring System
84 Keeping Wax Liquid for Application

Chemical-Vapor Deposition of $Cd_{1-x}Mn_xTe$

An experimental process makes films with interesting magnetic and magneto-optical properties.

NASA's Jet Propulsion Laboratory, Pasadena, California

Films of the dilute magnetic semiconductor alloy $Cd_{1-x}Mn_xTe$ have been deposited on glass and GaAs substrates by metalorganic chemical-vapor deposition (MOCVD). Devices made with $Cd_{1-x}Mn_xTe$ films are known to exhibit strong photoluminescence, stimulated emission, and magnetically-tunable lasing action. In addition, the energy-band gaps of such a material can be tailored by altering its composition — a property that gives flexibility in the development of high-efficiency cascade solar photovoltaic cells.

Dilute magnetic semiconductors have been previously deposited by molecular-beam epitaxy, which requires a high vacuum. MOCVD can be performed at atmospheric pressure, resulting in more-uniform films, covering a larger area, and enabling a higher production rate.

The experimental deposition system was contained in a horizontal quartz reactor tube equipped with a graphite susceptor heated by radio-frequency energy. The source of cadmium was dimethylcadmium (DMCd) held at a temperature of 0 °C, and the source of the tellurium was diethyltellurium (DETe) at 27 °C. The DMCd and DETe were carried into the tube by highly pure H_2.

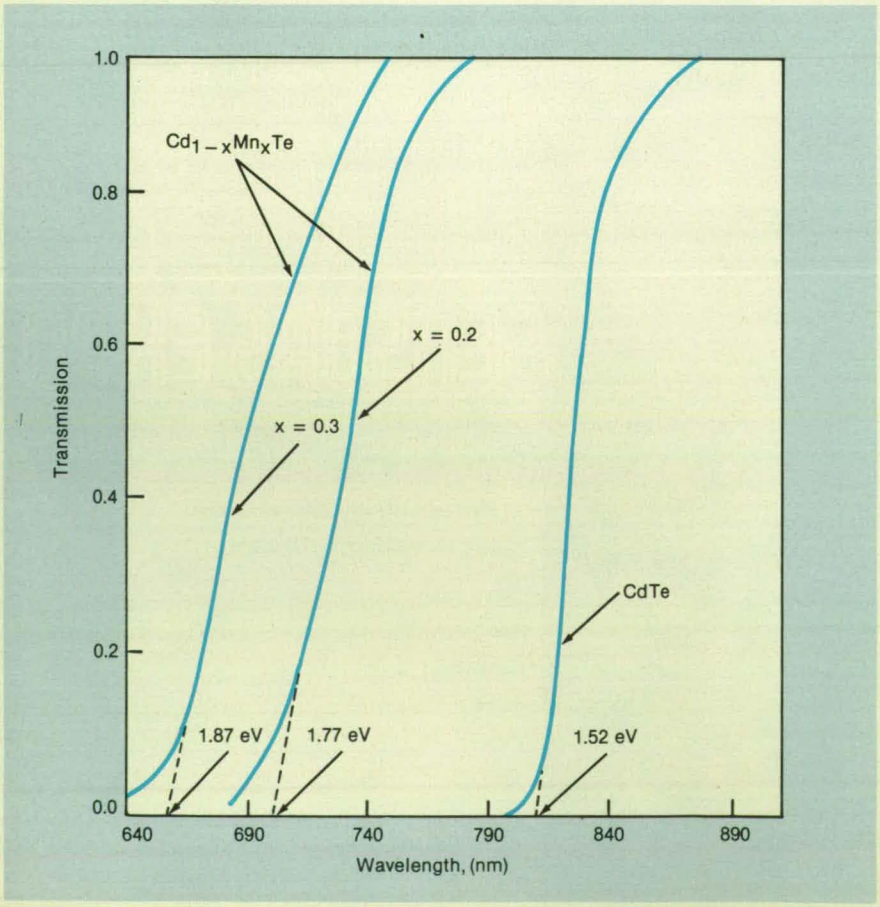

Figure 1. **The Optical Transmissions** of $Cd_{1-x}Mn_xTe$ films were measured and plotted as a function of wavelength to find the photon energy that equals the band-gap energy.

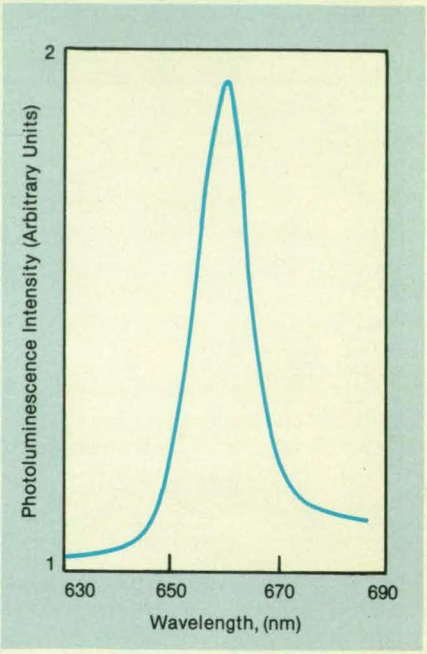

Figure 2. The **Photoluminescence Spectrum** of a specimen of $Cd_{0.75}Mn_{0.25}Te$ at a temperature of 10 K has a full width at half maximum of about 33 meV, indicating that the film has good crystalline quality.

The source of Mn was tricarbonyl(methylcyclopentadienyl) manganese (TCPMn), which is a liquid at room temperature. The hydrogen was bubbled through the TCPMn, which was heated to various temperatures between 120 and 140 °C to control the vapor pressure and, consequently, the concentration of the TCPMn. The tubes and valves carrying the TCPMn-laden H_2 and the front end of the reactor tube were heated to about 100 °C to prevent the TCPMn from condensing on them. The substrates were heated to temperatures of 410 to 450 °C, at which the metalorganic compounds decompose.

A series of depositions was made on glass substrates, and the optical transmissions were measured to determine the energy-band gaps, E_g (see Figure 1). Using the previously-known relation $E_g = 1.50 + 1.34x$ eV, it was then possible to determine the mole fractions, x, of Mn. X-ray diffraction scans of $Cd_{1-x}Mn_xTe$ films grown by MOCVD on GaAs matched those of $Cd_{1-x}Mn_xTe$ grown on GaAs by molecular-beam epitaxy. These films exhibited strong photoluminescence at temperatures of 10 to 15 K (see Figure 2).

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THOMSON SAGINAW

First in Linear Actuator Technology

Although CdTe films have smooth, mirrorlike surfaces, the addition of Mn sometimes causes ripples with dimensions of a few thousand Angstroms and a hazy appearance. However, better control of process conditions should eliminate these imperfections.

This work was done by Akbar Nouhi and Richard J. Stirn of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 49 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA's Jet Propulsion Laboratory [see page 14]. Refer to NPO-17399.

Making a Precisely Level Floor

A sequence of pouring operations ensures flatness and smoothness.

Marshall Space Flight Center, Alabama

A floor-pouring procedure yields a large surface that is level, smooth, and hard. The method has been used to fabricate a 1,200-ft^2 (111-m^2) floor that varies locally in elevation less than 0.015 in. in 16 horizontal in. (0.038 cm in 0.41 horizontal m) and slopes less than 20 s of arc from side to side.

The floor supports a 1,500-lb (680-kg) object on air bearings. The floor must be extremely level so that the object does not drift. The floor must also be extremely smooth so that an air-bearing gap of only 0.002 in. (0.0051 cm) can be maintained for adequate stiffness of the bearing.

The floor is made of a self-leveling, slow-curing epoxy with added black pigment. The epoxy is poured to a thickness no greater than 0.33 in. (0.84 cm) on a concrete base. The base floor should be seasoned, reasonably smooth and level, and at least 4 in. (10 cm) thick. The base should rest on a thermal barrier of gravel or cinders and should contain no steel plates, dividers, or bridges so as to minimize thermal distortion.

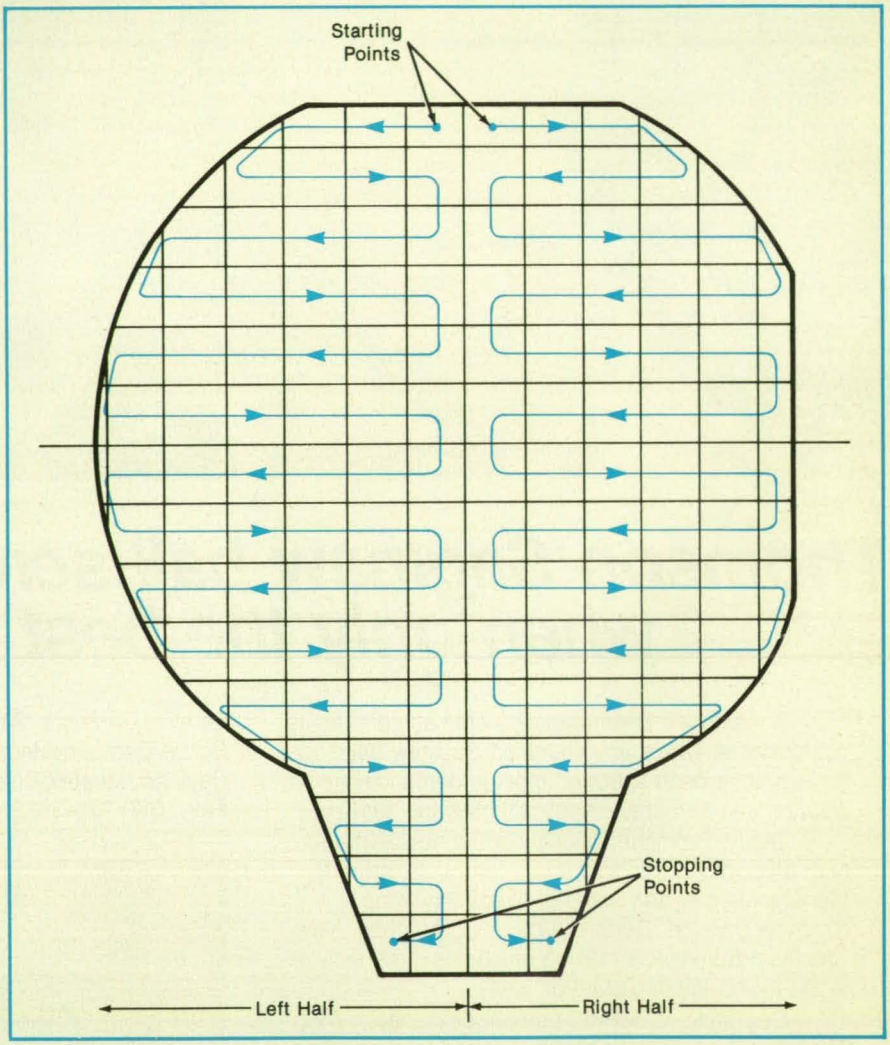
A metal retaining wall surrounds the base. The wall should be at least ½ in. (1.3 cm) higher than the poured floor. It should be sealed to contain the freshly poured mixture of epoxy and pigment and strong enough to absorb bumping by the object on the air bearings.

During pouring, two formulating machines supply epoxy through hoses while workers direct the flow. Workers continually supply the machines with raw materials until the job is done. A crew of 14 workers can pour the floor in 1½ h.

Even a self-leveling epoxy cannot spread itself out uniformly over such a large area. Accordingly, before pouring, the workers mark off the concrete subfloor with a grid of 3- by 3-ft (0.91- by 0.91-m) squares and partial squares (see figure). They surround a square or partial square with a sand-filled tube and fill it with the epoxy mixture, counting pulses from the pump to meter the correct amount. At the flow rate of about 6.3 in.^{3} (103 cm^3) per pulse, 68 pulses furnish the approximate amount of material for one square.

When a square or partial square has been filled, workers quickly rearrange the sand-filled tube to surround an adjacent square or partial square and fill it with the number of pulses necessary to cover the increment of area. Two groups of workers systematically fill blocks starting at opposite sides of the floor, each using a hose from one of the two formulating machines.

When all blocks have been filled, the machinery is turned off to minimize vibration and avoid kicking up dust while the epoxy cures. Meanwhile, workers eliminate air bubbles that rise to the surface. Moving on a catwalk suspended over the floor, they direct hot-air guns on extension handles into the bubbles to burst them.

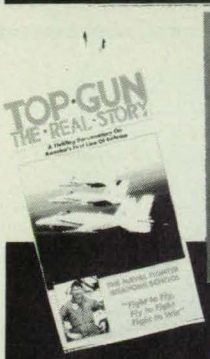


A **Grid Defines Incremental Areas** for pouring the epoxy floor. Workers use the block numbers to follow a systematic pouring sequence, as shown by the serpentine arrows. One team pours the right half while the other pours the left half. The generally circular area is for maneuvering the test object. The smaller, trapezoidal area is for storage, entry, and egress.

The newly poured floor is then left totally undisturbed — even by strong air currents — for 10 days. Another 20 days of hardening should be allowed before heavy loads are placed on the floor.

This work was done by William G. Simpson, William H. Walker, Jim Cather, John B. Burch, Keith M. Clark, and Dwight Johnston of **Marshall Space Flight Center** *and David E. Henderson of Sperry-Rand Corp. For further information, Circle 56 on the TSP Request Card.*

MFS-28306



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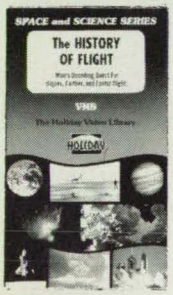

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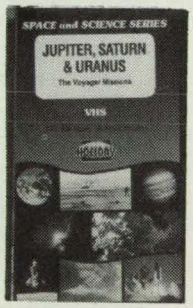

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Making Multicore, Multishell Microspheres

Multiple streams of fluids would be combined to produce various structures.

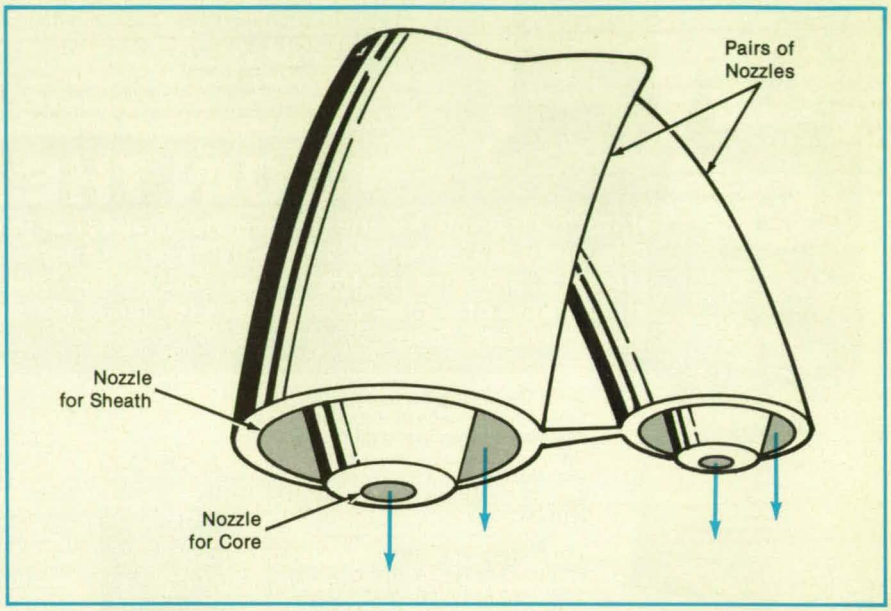
NASA's Jet Propulsion Laboratory, Pasadena, California

Spherical or nearly spherical microshells containing two or more discrete inclusions, like eggs with more than one yolk, would be produced by a proposed technique. For example, a glass shell might hold a bubble of hydrogen adjacent to one of oxygen.

If desired, the spheres could be designed so that the cores combine to mix or react only after leaving the shell generator. Similarly, two or more shell-wall materials could mix or react after leaving the generator.

The technique would involve two (or more) pairs of coaxial nozzles (see figure). The converging jets of fluids from the separate nozzles would combine by surface tension, forming a liquid bridge of dog-bone-shaped cross section. The stream would eventually contract into a round cross section and break up into droplets. The apparatus could deliver one, two, or more different outer-shell-material streams with one, two, or more different core materials, each entrained in its own outer stream.

The droplet shells would solidify by freezing or by chemical reaction. The shell would be more or less spherical, but the precise shapes would depend on centering forces, surface tensions, temperatures, and aerodynamic and gravitational forces acting on the falling droplets. The extent of mixing or reaction of the shell and filler materials would depend on such properties of the materials as the viscosity and surface tension and on such controllable system parameters as the temperature, velocities, and volumes of the droplets.



Pairs of Coaxial Nozzles would be combined in arrays of two or more. Each pair of nozzles would generate an inner jet surrounded by a sheath of fluid. The multiple jets would combine to form droplets composed of shells and cores.

This work was done by Andrew D. Morrison of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 44 on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Resident Office-JPL [see page 14]. Refer to NPO-17203.

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Circularity-Measuring System

A shape gauge is designed especially for use on large objects.

Marshall Space Flight Center, Alabama

A shape gauge and an associated computer constitute a system that measures the deviations of large cylinders from roundness. Intended originally for use on the solid rocket boosters of the Space Shuttle, the system can also be used to measure the straightness, roundness, or complicated shapes of such large geometrical objects as the surfaces of aircraft and the hulls of ships.

The gauge (see Figure 1) has arms with two fixed end points, the distance between which is precisely 36 in. (914.4 mm). An outwardly-spring-loaded probe slides along the perpendicular bisector of the line between the fixed points and measures small displacements within 0.0001 in. (0.0025 mm). Roll and pitch sensors help the technician to level the gauge for maximum accuracy. Pins can be attached to the arms near the end points and to points near the probe, to mate with guide holes (if provided) in the object to be measured.

The technician measures the displacements at a sequence of positions around the circumference of the object. This could be done most conveniently by using the guide pins and indexing the gauge to a circumferential string of guide holes. The measured displacements are sent to the computer.

For each measurement, the portion of the measured surface between the end points can be approximated by the circular arc tangent to the end points and to the end of the probe. The computer calculates the arc for each measurement. It pieces together the arcs from the sequence of measurements to obtain a curve, consisting of circular-arc segments, that approximates the measured surface (see Figure 2).

This work was done by Walter B. Whippo, G. R. RohrKaste, and John E. Miller of Morton Thiokol, Inc., for **Marshall Space Flight Center**. *For further information, Circle 129 on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 14]. Refer to MFS-28313 *(See page 84 for Figure 2)*

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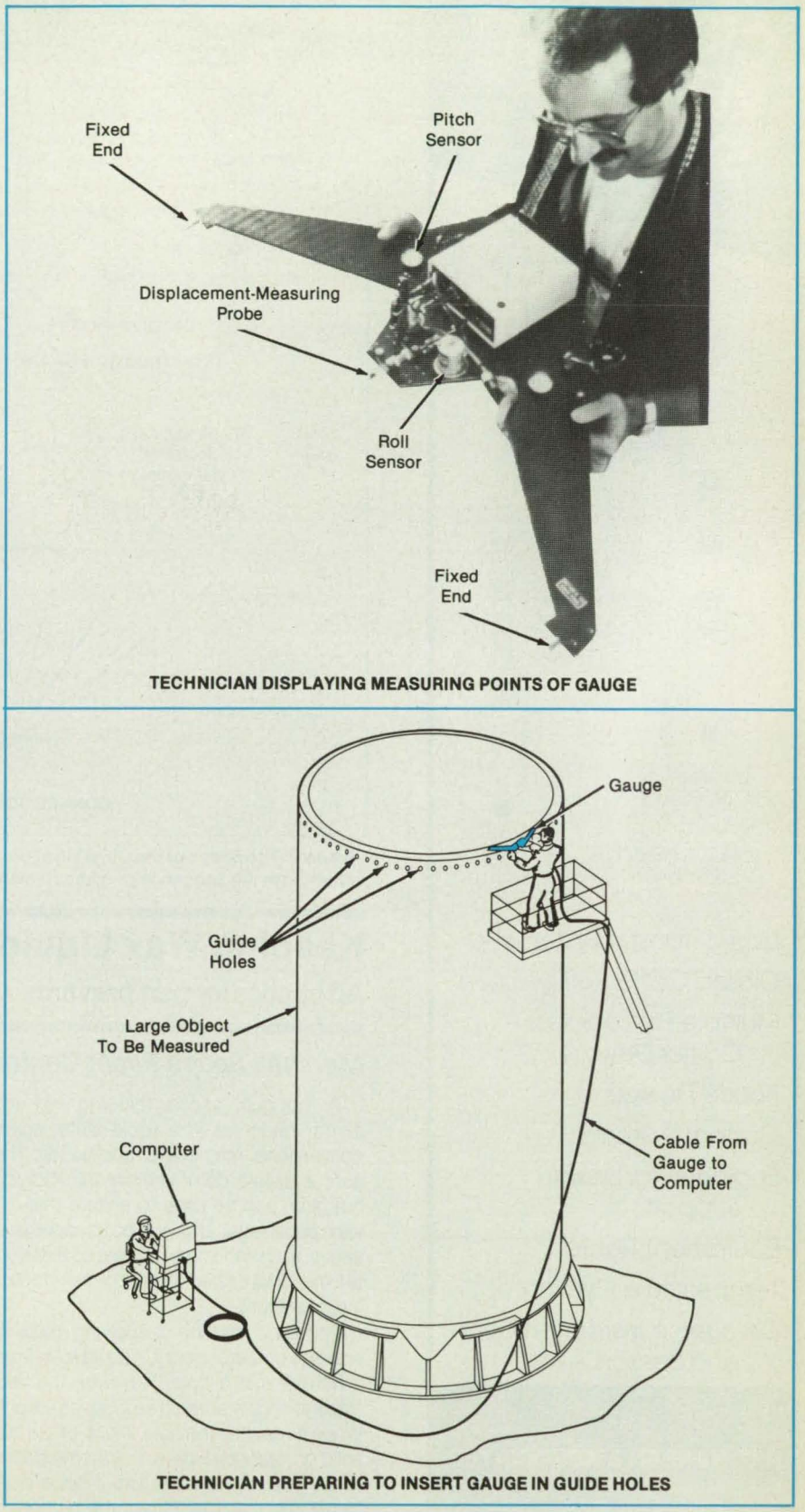
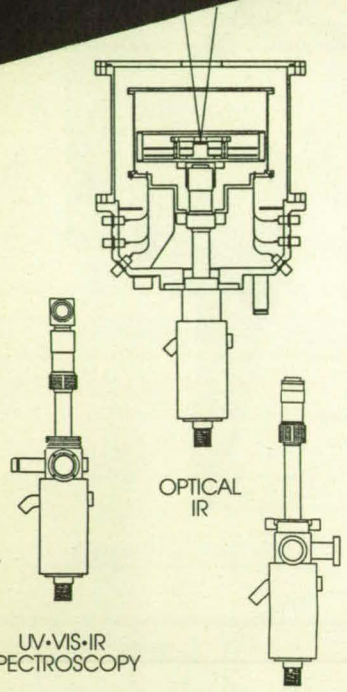


Figure 1. **Shaped and Held Somewhat Like a Crossbow**, the shape gauge measures the relative locations of three points on the surface of a large, round object. By making a connected series of measurements around the periphery, a technician using the gauge can determine the deviation of the object from perfect circularity.

CRYOGENIC RESEARCH SYSTEMS



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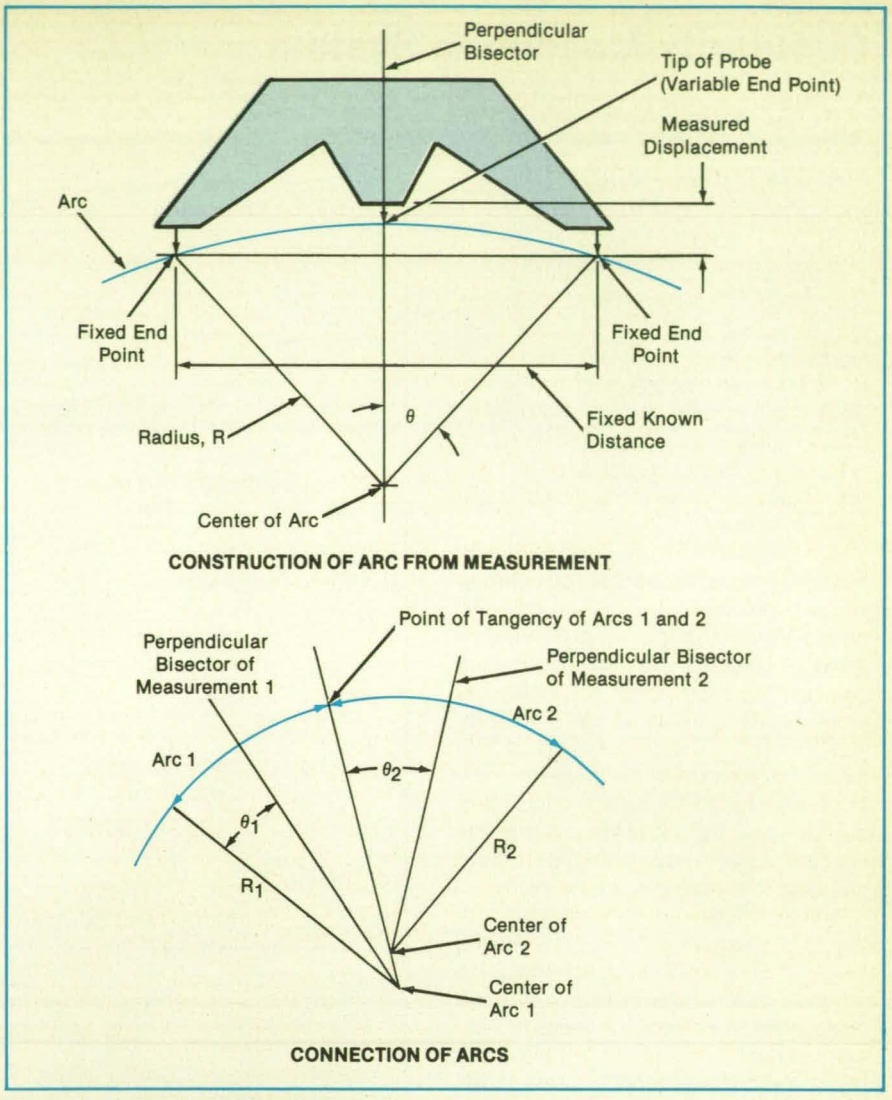

Figure 2. The **Shape of the Object** is approximated by piecing together the circular arcs computed from the sequence of measurements around its periphery.

Keeping Wax Liquid for Application

An applicator gun prevents wax from congealing prematurely.

Marshall Space Flight Center, Alabama

A "hot gun" applies masking wax and similar materials in a liquid state, unlike conventional methods of application. The gun, available commercially for applying hot glue, can be used to ensure that the wax penetrates and fills holes, flow passages, and manifold passages so that contamination is sealed off during manufacturing operations.

The usual method of applying masking wax is to spoon or pour it in liquid form from a hot pot into a hole. However, the wax starts to solidify as soon as it leaves the pot. When it reaches the hole, much of it is in a solid or near-solid state. It adheres poorly to the wall of the hole, and it flows sluggishly into the hole. Often, the hardening wax must be pushed into the hole. As a result, the seal is imperfect, and repeated applications are needed. Meanwhile, an excess of wax builds up and must be removed for inspection of the seal.

With the hot gun, in contrast, the holding chamber and the nozzle supply continuous heat to the wax, and the wax can be injected directly into the hole as a liquid. Nozzles of various sizes can be interchanged so that one can select a nozzle that has an opening suited to the viscosity of the wax and the size of the hole in a particular application. The trigger mechanism of the gun meters the wax so that excess material does not build up. The hot gun is fast, eliminates repeated application, and greatly reduces cleanup time.

This work was done by Russell V. Meyer of Rockwell International Corp. for **Marshall Space Flight Center**. *No further documentation is available.*
MFS-29238

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Mathematics and Information Sciences

Hardware Techniques, and Processes

85 Automatic Parametric Testing of Integrated Circuits

Book and Reports

85 Exponential Finite-Difference Technique

88 Inversion of Jacobian Matrix for Robot Manipulators

Automatic Parametric Testing of Integrated Circuits

A software system generates its own test instructions and teaches itself new tests.

NASA's Jet Propulsion Laboratory, Pasadena, California

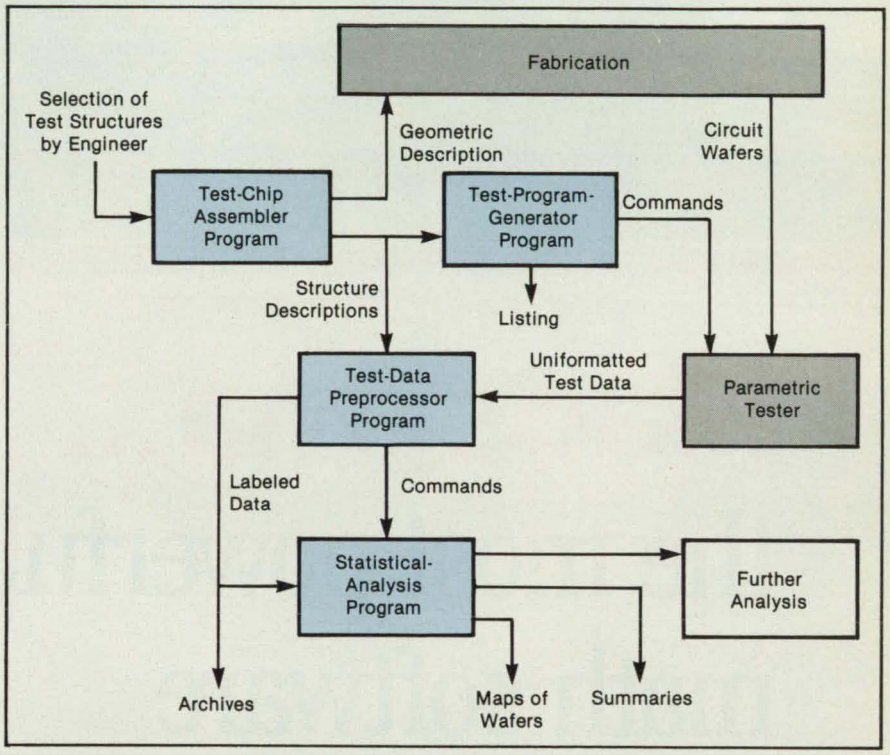
A computer program for parametric testing saves time and effort in research and development of integrated circuits. The software system automatically assembles various types of test structures and lays them out on a silicon chip, generates a sequence of test instructions, and interprets the test data. The system employs self-programming software; it needs a minimum of human intervention. It can be adapted to the needs of different laboratories and can readily accommodate new test structures.

The designer of an integrated circuit decides on the type and number of test structures — transistors of various polarities and sizes, split-bridge resistors, van der Pauw crosses, and the like. With this information, the system automatically generates the geometrical specifications for the test structures that are to be built into the integrated circuit. The specifications are used to fabricate silicon wafers containing the circuit (see figure). Meanwhile, the system produces instructions for testing the chip.

If the engineer devises a new test structure, the system teaches itself how to specify and lay out the new structure and determines how it should be tested. The engineer merely adds a few lines about the new structure in a declaration file; the engineer does not have to make any changes in the test-program-generator portion of the software.

The program reduces the large amount of data on the structures to statistical summaries for individual wafers and for entire lots of wafers. Additional programs use the statistical summaries to perform such tasks as high-level analysis, extraction of parameters, and mapping of wafers.

The program codes are designed to be adaptable to most computers and test equipment now in use. They are written in high-level languages to enhance transportability.



The **Parametric-Testing Software System** proceeds from the engineer's selection to control automatically the fabrication of test structures in integrated circuits, the operation of the testing equipment, and the analysis of the test data. The system also produces program listings in easily read form.

This work was done by Glenn A. Jennings and Cesar A. Piña of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, Circle 68 on the TSP Request Card.*
NPO-16783

Books and Reports

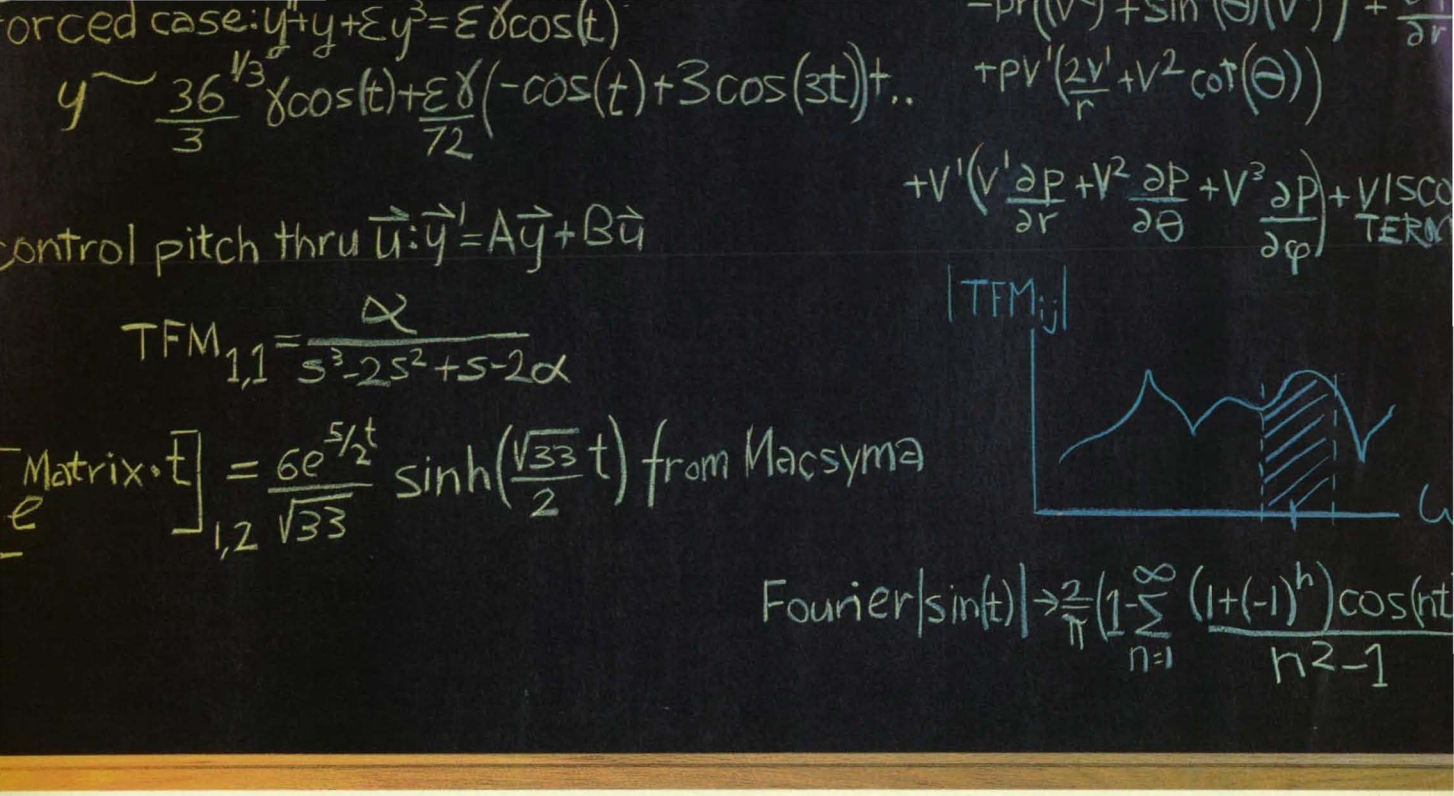
These reports, studies, handbooks are available from NASA as Technical Support Packages (TSP's) when a Request Card number is cited; otherwise they are available from the National Technical Information Service.

Exponential Finite-Difference Technique

Various partial differential equations are solved numerically.

A report discusses the use of an explicit exponential finite-difference technique to solve various diffusion-type partial differential equations. Previously, the technique was applied only to transient-heat-transfer problems in one dimensional Cartesian coordinates. This study extends the technique to transient-heat-transfer problems in one dimensional cylindrical coordinates and two and three dimensional Cartesian coordinates and to some nonlinear problems in one or two Cartesian coordinates.

As an application of the finite difference technique, the linear, two-dimensional Cartesian, transient, diffusion-type equation for temperature in an isotropic medium is treated by the classical method of separation of dependent variables. The separated-variable ratio that contains the temporal derivative leads immediately to



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the expression of the transient effect in a multiplicative exponential term in time. The separated-variable ratio that contains the partial spatial second derivatives is approximated by a finite-difference term for the temperatures at four adjacent grid points at one time step.

The two separated-variable ratios are equated to the exponential time parameter and thus combined to obtain the single explicit, finite-difference expression for the temperature at the next time step:

$$T_{ij}^{n+1} = T_{ij}^{n} \exp\{\Omega M_{ij}\}$$

where T = temperature, the superscripts denote the time steps, the subscripts denote the grid points, M_{ij} is the four-grid-point, finite-difference form of the separated-variable ratio for the Laplacian of temperature at the nth time step, and Ω is a dimensionless time parameter that combines the effects of the diffusivity and the grid spacing. The time step can be divided into $m + 1$ subintervals to improve the convergence of the solution by writing

$$T_{ij}^{n+1} = T_{ij}^{n} \exp\{[\Omega/(m+1)] \sum_{p=0}^{m} M_{ij}^{n+p/(m+1)}\}$$

The equations obtained in an analysis of the cylindrical problem are similar, except that M_{ij} is reduced to the one-dimensional form M_i and contains a radial-expansion term.

The time step and grid spacing must be made small enough to assure numerical stability. The divergence or convergence of the solution is easily expressed in terms of the growth of the exponential at each step, and, as a result, the criteria for stability are conveniently expressed as conditions on M_i or M_{ij}, or on the size of the dimensionless time subinterval $\Omega/(m + 1)$.

Boundary and initial conditions are treated in a straightforward manner by suitable numbering of grid points and substitutions of known temperature values into the expressions for M_i^n and M_{ij}^n. Where a flux of heat is specified at a boundary, the use of that specified difference of temperature across the boundary that determines the specified flux must be used.

The nonlinear cases considered in this study are the viscous Burger's equation and the steady-state equation for boundary-layer flow over a flat plate. In both cases, the differential equation must be linearized.

The exponential finite-difference technique was compared with several other numerical techniques and with exact solutions (where available) in application to several heat-transfer and flow problems. The exponential-finite-difference solutions were closer than the others to the exact solutions in those problems for which exact solutions were available.

This work was done by Robert F. Handschuh of the U.S. Army Aviation Research and Technology Activity for **Lewis Research Center**. *Further information*

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may be found in NASA TM-89874 [N87-24930], "An Exponential Finite Difference Technique for Solving Partial Differential Equations."

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
LEW-14737

Inversion of Jacobian Matrix for Robot Manipulators

A closed-form transformation from task space to joint space is computed efficiently.

A report discusses the inversion of the Jacobian matrix for a class of six-degree-of-freedom arms with spherical wrist, i.e., with the last three joints intersecting. The authors show that by taking advantage of the simple geometry of such arms, the closed-form solution of $\mathbf{Q} = J^{-1}\mathbf{X}$, which represents a linear transformation from task space to joint space, can be obtained efficiently.

The inverse transformation, represented as $\mathbf{Q} = J^{-1}\mathbf{X}$, is essential for the implementation of the advanced task-space control schemes since the actuation; i.e., the application of forces/torques is ultimately performed at the joints level. However, while the forward transformation, given as $\mathbf{Q} = J\mathbf{X}$, presents no major problem, the computation of the inverse transformation is more difficult, and previous authors have studied ways to perform it efficiently. The main motivation in the development of the previous methods has been to avoid the prohibitive computational cost, which arises from the symbolic or numerical computation of the Jacobian and its numerical inversion.

The theoretical development in this paper involves the derivation of the Jacobian vectorial matrix, which is a general form of the Jacobian from which specific Jacobians can be derived by a set of appropriate transformation, i.e., velocity reference point transformation as well as projection onto the applicable coordinates. The authors develop a relatively simple method in which the Jacobian vectorial matrix and corresponding transformations are derived by relating the velocity of two points. It is shown that any specific Jacobian can be described in terms of another Jacobian with arbitrary choice of velocity reference point and coordinate frame, which can be chosen to yield the Jacobian in its simplest symbolical form leading to its symbolic inversion and the closed-form solution of $\mathbf{Q} = J^{-1}\mathbf{X}$.

The report presents solutions for a PUMA arm, a JPL/Stanford arm, and a six-revolute-joint coplanar arm along with all singular points. The solution for each joint variable is found as an explicit function of the singular points, thus providing better insight into the effect of the singular points on the motion of, and force/torque exerted by, each joint.

The main contribution of this paper is to show that the simple geometry of this type of arms can be exploited in performing the inverse transformation without any need to compute the Jacobian or its inverse explicitly. The cost of computing the inverse transformation becomes of the same order as that of the cost of computing forward kinematic position transformation, and it is significantly reduced if this transformation is already performed. The implication of this computational efficiency is that advanced task-space control schemes for spherical-wrist arms can be implemented more efficiently.

This work was done by Amir Fijany and Antal K. Bejczy of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Efficient Jacobian Inversion for the Control of Simple Robot Manipulators," Circle 125 on the TSP Request Card.*
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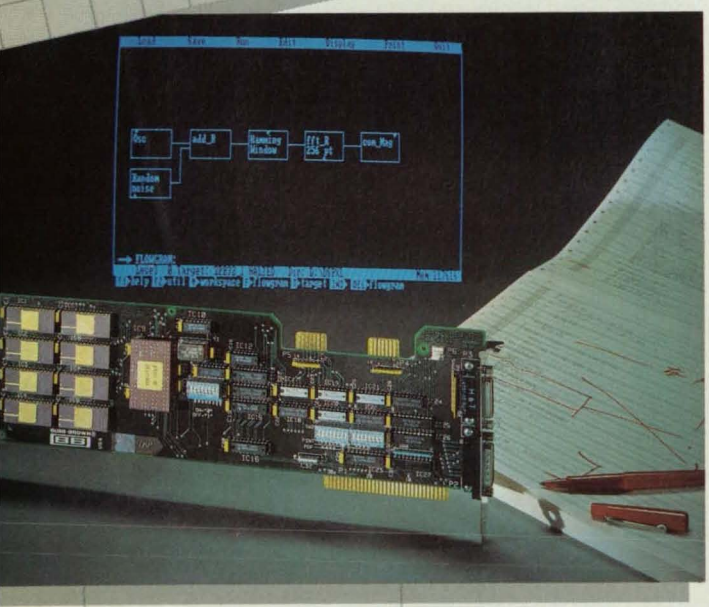

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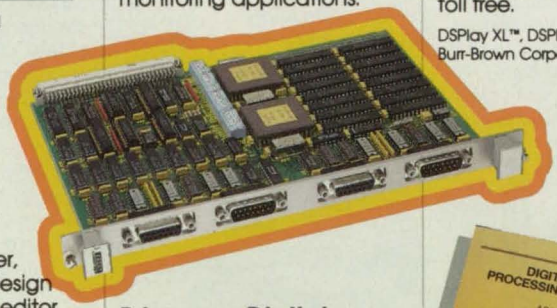

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New on the Market

Melles Griot Inc., Irvine, CA, has developed a compact 120-watt **carbon dioxide laser** for industrial applications. The laser head weighs 60 pounds and is completely sealed, requiring only 280 VAC power and 6 liters/minute cooling water. The portable unit offers +8% long-term amplitude stability, a 5.5 mm beam diameter, and a 350-nanosecond standard pulse decay time, with optional 150-nanosecond performance available.
Circle Reader Action Number 750.

The Model 2220 solid-state **monochrome video camera** from CIDTEC Inc., Liverpool, NY, features a progressively scanned 256 x 256 binary format CID array that matches standard memories for efficient computer interfacing. The camera's square pixels simplify processing algorithms and its contiguous structure ensures accurate image detail. A frame reset function allows users to adjust frame size for high-speed variable output.
Circle Reader Action Number 790.

Triumph, a new **rust converter** and primer coating from United Laboratories Inc., Addison, IL, instantly turns rust into phosphates for easy removal without scraping or sandblasting. The phosphating paint, which cures rock-hard, covers up to 530 square feet per gallon and can be applied with a brush or diluted with water for spray applications. It contains no lead or solvents, is compatible with wet surfaces, and tolerates extreme temperature changes without cracking or peeling. A gallon costs $59.00.
Circle Reader Action Number 794.

NCUBE, Beaverton, OR, has unveiled a **massively parallel supercomputer** with unprecedented processing speed. The 6400 Series Scalar Supercomputer uses up to 8192 processors to achieve a maximum performance of 100 billion instruction executions per second and 27 billion scalar floating point operations per second. Because the processors can operate independently in parallel, the 6400 is ideally suited to simulating and performing calculations upon dynamic processes involving many different variables. Potential applications include structural and chemical analysis, fluid dynamics, artificial intelligence, signal processing, and robotics.
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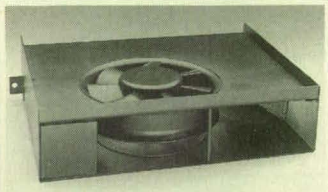

The Diplomat™, an aerodynamic **blower** developed by Comair Rotron, Saugerties, NY, features a diffuser mounting that reduces noise and improves air flow, a foam scroll that deadens sound, and a seven-bladed propeller with a patented feather edge. Targeted for the mini-to-mainframe computer market, the Diplomat can be custom-configured to fit a wide range of dimension and air flow requirements.
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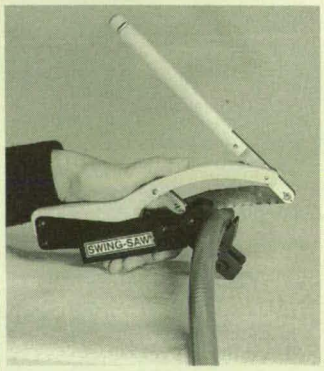

The Seatek Company Inc., Stamford, CT, has combined a gripping vise and a miniature hacksaw to create a new labor-saving **hand tool** called the Swing-Saw Sealtite Cutter. The top lever, which actuates the saw blade, provides leverage for a strong cutting action, while the hacksaw hinged to the vise makes precise square cuts each time. The Swing-Saw can cut copper and steel tubing, threaded rods, and cables up to 1.5 inches in diameter.
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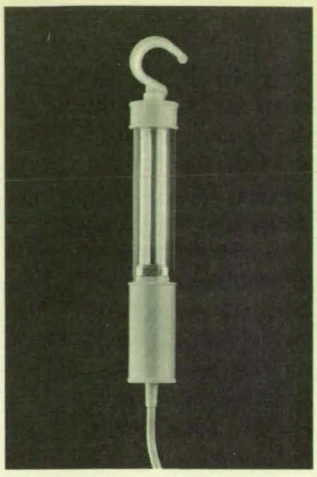

The new KH 500 **fluorescent work light** with 13-watt U-lamp produces as much light as a 60-watt caged incandescent but lasts ten times longer, according to the manufacturer, KH Industries of Angola, NY. Available with a 25 or 50 foot neophrem jacket, the portable light is sealed against moisture, dust, and vapors. Its shatterproof butyrate tubeshield protects against damage from falling objects, flying glass, and sparks.
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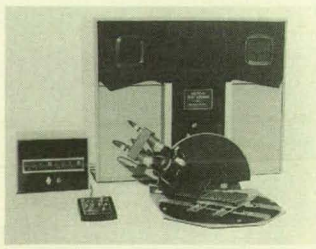

Metron Optics Inc., Solana Beach, CA, has developed a **three-dimensional video system** that forms realistic images in mid air. Especially useful for remote viewing of hazardous areas, the stereoptical system employs two video cameras and a 3D monitor to create flicker-free color pictures with natural depth. Metron also manufactures a 3D video microscope with 360 degree rotation and plans to offer 3D recording on videotape using a super VHS recorder with stereophonic sound.
Circle Reader Action Number 788.

AT&T Microelectronics has unveiled the fastest **digital signal processor** (DSP) to date—a 25-nanosecond chip that processes data at 40 million instructions per second. Since just one 25-ns DSP chip can perform jobs that previously required several devices, designers can use the new chip to conserve valuable board space. Now available in sample quantities, the processor is suited for telecommunications and computer applications, such as modems, digital cellular phones, laser printers, and optical character recognizers.
Circle Reader Action Number 760.

Charleswater Products Inc., West Newton, MA, is offering samples of REZTORE™, an **antistatic cleaner** that removes dust, grime, solder, grease, and fingerprints from conductive and insulative work surfaces. The product features zero ionic contamination, contains no amines, cleans without abrasion, and leaves no insulative residue or film. Effective at cleaning vinyl and rubber mats, high-pressure laminates, metal, glass, and plastic, REZTORE comes in an 8-ounce pump spray, trigger spray quart bottle, or gallon container.
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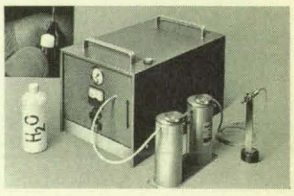

The Spirflame, a self-contained **gas production unit** from Solder Absorbing Technology Inc., Springfield, MA, can generate a flame small enough to thread through the eye of a needle or large enough to cut 2 mm steel. Flame temperature and size are electronically stabilized at the selected intensity. The device produces gas from the electrolysis of water and is useful for soft soldering, brazing, fusion welding, flame polishing, and other industrial applications.
Circle Reader Action Number 778.

A powerful new software product that **extends hypertext technology** into the realm of true information analysis has been introduced by the Envos Corp., Mountain View, CA. The software, called Envos Notecards, is useful for organizing and analyzing large amounts of textual data. Among its features are graphics editors for creating onscreen "notecards" of whole documents; overlapping windows that allow multiple notecards to be viewed concurrently; a "browsing" function that enables users to view and manipulate the entire card network, and automatic conversion of cards into printed documents. Envos Notecards runs on Sun workstations.
Circle Reader Action Number 766.

New on the Market

The 700 Series Polycorder®, a **portable data logger** designed for industrial testing, is now available from Omnidata International Inc., Logan, UT. The battery-powered unit contains up to 448 K-bytes of memory and a 12-bit A-D section that can scan more than 75,000 samples per second. Standard features include an RS-232 port, ten analog channels, eight digital I/Os, a synchronous hardware trigger, and two direct accelerometer inputs. The Polycorder is fully programmable, enabling the user to develop an infinite number of data collection algorithms.
Circle Reader Action Number 800.

Science/Electronics, Dayton, OH, is marketing a line of battery-powered **data loggers** with direct RS-232 serial interface. The systems, dubbed Squirrel Meter/Loggers, offer multiple input and can store up to 42,000 readings on board in RAM. Users can record temperature, voltage, current, pulses, 8-bit inputs, or events. Logging includes real-time documentation. The low-power CMOS circuitry permits unattended recording runs for up to six months.
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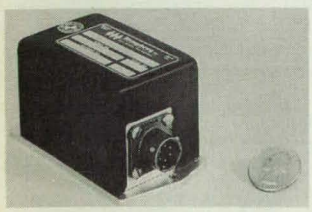

A new series of subminiature precision DC-DC rate **gyroscopes** has been developed by Humphrey Inc., San Diego, CA. Fluid-filled for precise damping and shock protection, the tiny (2.0″ × 2.0″ × 3.5″) gyros are designed for demanding rate control requirements, such as fire control systems, antenna stabilization, aircraft control, and missile systems. They come in rate ranges from 40 to 1000 degrees per second with natural frequency of 20 to 140 Hz.
Circle Reader Action Number 758.

The 400 Series **digital oscilloscope** from Nicolet Test Instruments, Madison, WI, offers a record 256K work memory per channel and permits cascading together four channels for memory as long as 1 megasample. This memory is complemented by a standard 32-bit CPU, providing waveform processing up to 100 times faster than interfacing with a PC. Available in two- and four-channel models, the 400 Series also features a 44-megabyte hard disk, a transportable floppy drive for automated testing, easy-to-use front panel controls, and IEEE-488.2 interface software.
Circle Reader Action Number 756.

The new Challenge 3000 modular **workstations** can be tailored to each operation or task, resulting in more cost-efficient and productive use of factory space. Designed by Advance Engineering, North Hollywood, CA, the stations can be configured as individual units or single- and double-sided assembly lines. A unique utility distribution system allows power, air, and other utilities to be passed from one unit to another. Work surfaces, light fixtures, and shelving are adjustable for maximum operator efficiency and convenience.
Circle Reader Action Number 762.

Working from a palette of 16.7 million colors, Polaroid's new **Bravo Computer Slide Maker** (BCSM) creates boardroom-quality images with up to 8,000 lines of addressable resolution. The digital film recorder produces both instant and conventionally-processed 35mm slides at a fraction of the cost of outside slide services, according to the manufacturer. Available in either IBM- or Apple Macintosh-compatible versions, the BCSM simply plugs into the host computer and is ready to go.
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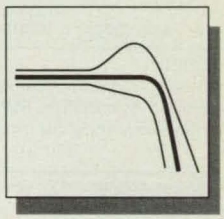

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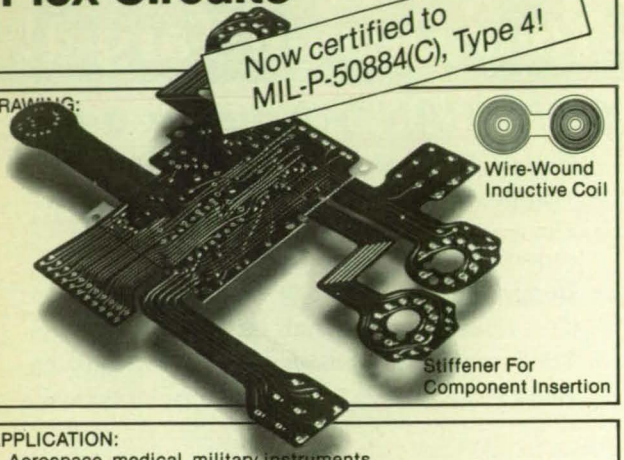

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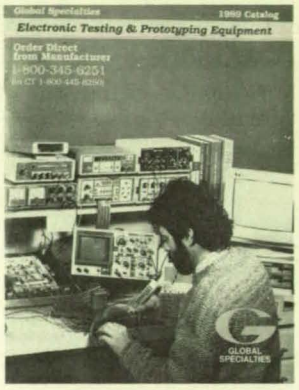
New Literature



A 32-page catalog of **electronic testing and prototyping equipment** is now available from Global Specialties, a division of Interplex Electronics, New Haven, CT. Offered free of charge, the catalog features Global's breadboarding products, logic test devices, power supplies, test instruments, and accessories. New products include the DSA-250, a low-cost digital storage adapter, and a line of data communications equipment.
Circle Reader Action Number 702.

A 24-page catalog describes **cleaning and preventive maintenance products** from the Texwipe Company, Upper Saddle River, NJ. Distributed free of charge, the publication is divided into seven product categories: wipers, clean room wipers, solvents and cleaning solutions, swabs and facemasks, premoistened pads, compressed gas, and cleaning kits. A color-coded index enables users to quickly match applications to products.
Circle Reader Action Number 712.

Electrospec Inc., Dover, NJ, is offering a free 216-page **network communications catalog**. Featured products include baluns, cable assemblies, connectors, couplings, interconnect hardware, fiber optic components, switch boxes, cabinets, panels, and networking tools. The catalog contains product photographs and a glossary.
Circle Reader Action Number 722.

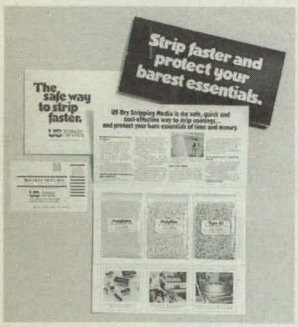
A new line of **super precision bearings** is described in a catalog from the Torrington Company, Torrington, CT. The 95-page publication provides specifications for 20 styles of precision bearings for machine tools, pumps, compressors, and other exacting applications. In addition, the catalog reviews key considerations in bearing selection, such as mounting arrangement, balance, bearing geometry, alignment of rotating parts, and lubrication.
Circle Reader Action Number 716.

NYRIM®, a new **thermoplastic** designed to withstand heavy wear and tear in hostile environments, is featured in a free brochure from CUE Inc., Mars, PA. Produced by chemically bonding a copolymer of nylon -6 to an impact-resistant elastomer, NYRIM is easily cast into stock shapes —including rod, tube, and sheet—which can then be machined into such finished parts as automotive cooling fans, gears, pulleys, machine housings, pump impellers, and filter plates. The four-color brochure outlines advantages the thermoplastic offers over metals, and includes a list of typical properties.
Circle Reader Action Number 724.

A guide to **aerospace propulsion forgings** is available from the Shultz Steel Company, South Gate, CA. Product highlights include rotating part forgings (shafts, disks, and impellers) for gas turbine engines; turbine rings, casings, domes, and nozzles; and rocket engine parts. The free brochure also details the company's quality control of metallurgical microstructures and computer simulation capabilities.
Circle Reader Action Number 708.

New Literature

A four-color engineering manual and catalog from Disogrin Industries, Manchester, NH, provides design, selection, and application data for a variety of **hydraulic seals**, including U-cup seals, rod wipers, piston seals, flange packings, O-rings, and wear rings. Schematic drawings clarify design and installation procedures, while tables, graphs, and curves offer information on chemical compatibility, tear strength, abrasion resistance, and other key factors in seal selection.
Circle Reader Action Number 710.



US Technology Corp., Danielson, CT, has produced a brochure that explains the benefits of **dry stripping** paint and other surface contaminants from aircraft and electronic components. As a replacement for hazardous chemical strippers, dry stripping eliminates expensive disposal problems, according to the brochure, which includes sample packets of three media hardness grades: PolyPlus®, PolyExtra®, and Type III®. Relative hardness is discussed and correlated to performance on a variety of surfaces, including composites.
Circle Reader Action Number 718.

"Magnetics For Telecommunications," a new catalog from Prem Magnetics Inc., McHenry, IL, features more than 80 **coupling transformers for voice and data applications**. Products include feedbridge inductors, single hybrid transformers, and a new series of telephone interconnect transformers that have received British Standard Institute (BSI) approval.
Circle Reader Action Number 714

Heat transfer equipment for aircraft, aerospace, electronics, and other high-technology industries is highlighted in a color brochure from the affiliated companies of Lytron and Alpha United. Aluminum heat exchangers are displayed in many configurations, including oil coolers, evaporators, condensers, cryogenic heat exchangers, and bleed air coolers. The free brochure also describes cold plates, cold walls, and cooling enclosures for high-density electronics systems.
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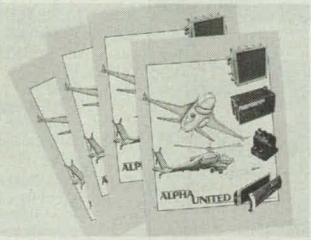

More than 2,000 **programmable devices** are featured in a new booklet from Logical Devices Inc., Fort Lauderdale, FL. Organized by manufacturer and device architecture, the booklet specifies which LDI programmer supports each device, or if future support is planned. Information on device technology includes number of pins, array size, and voltage.
Circle Reader Action Number 706.

Applications for more than 200 **thermal spray and plasma transferred-arc coatings** are outlined in a free brochure from General Plasma, East Windsor, CT. The four-page publication lists OEM specifications for wear-resistant, corrosion-resistant, thermal barrier, abradable, dielectric, conductive, dimensional restoration, and medical implant coatings.
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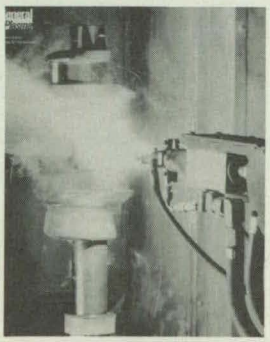

The Yokogawa Corp. of America, Newnan, GA, is offering a free **strip chart recorder selection guide**. The fold-out wall poster identifies and defines recording methods, higher-level functions, signal inputs, and printing options.
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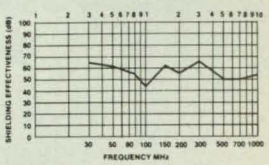

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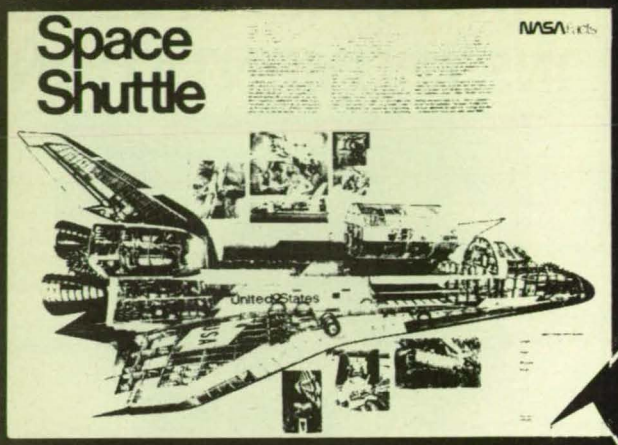

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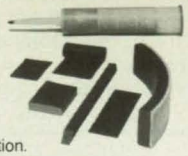

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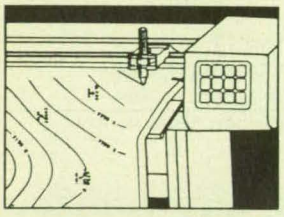

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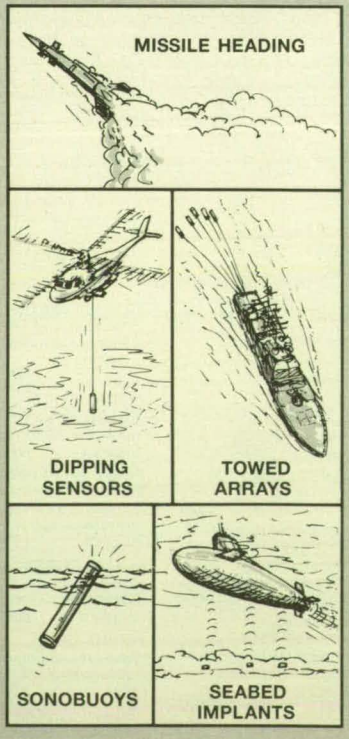

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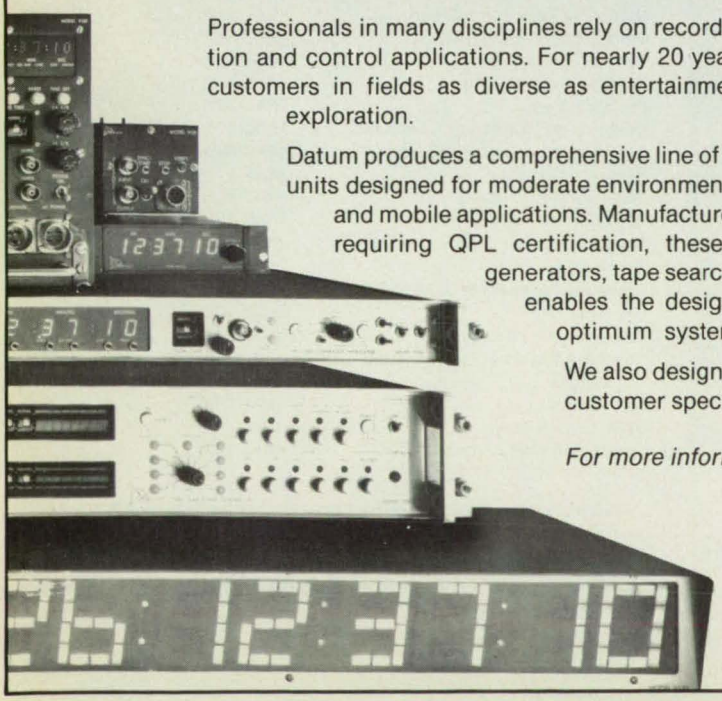

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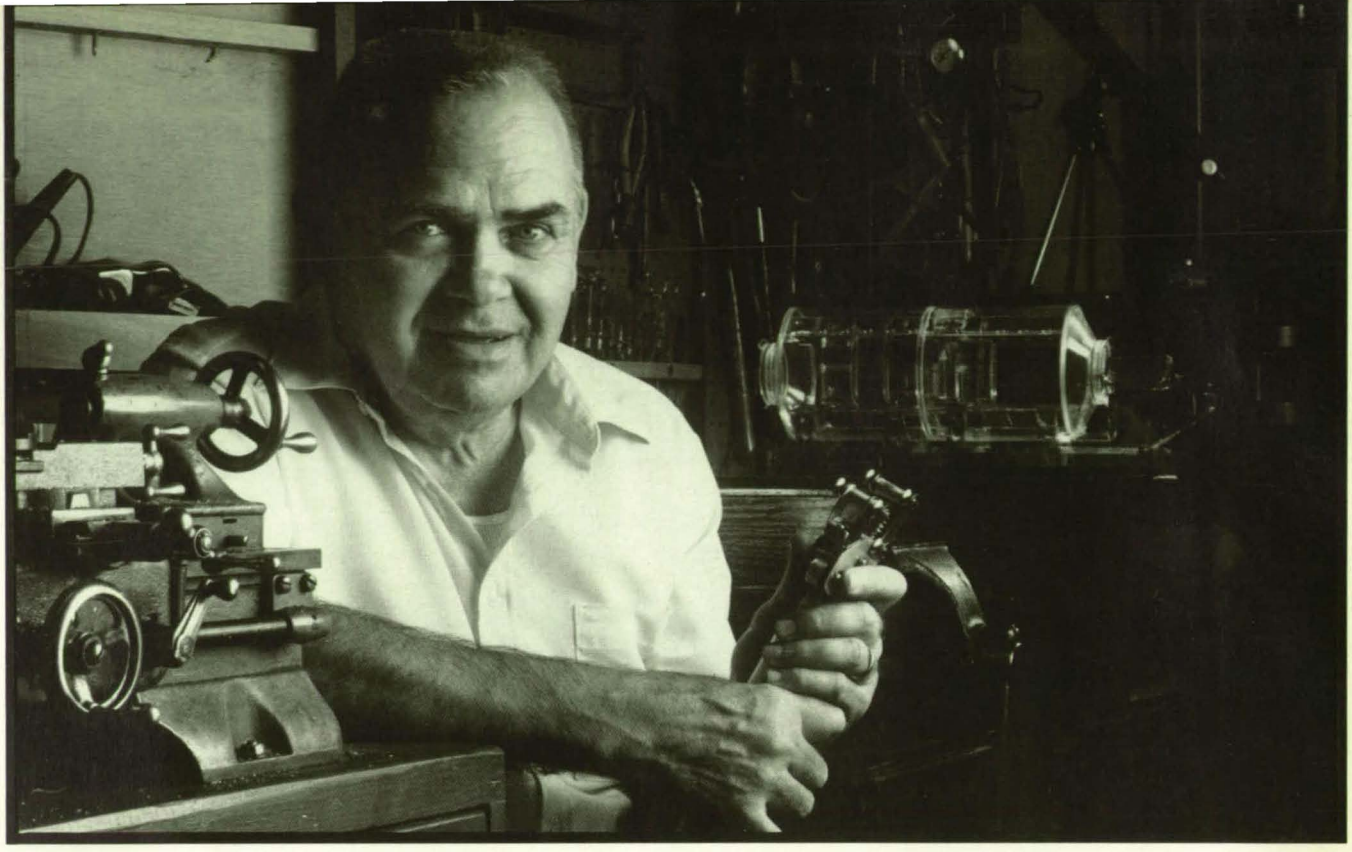

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